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Sloan School of Management Working Paper #1890-87

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Substantial attention has been focused on possible declines in airline safety as a consequence of economic deregulation during recent years. There has, however, been relatively little analysis of the effect of firms' financial conditions on their safety performance. This paper uses two kinds of data to evaluate claims that deregulation has reduced air safety. First, I examine aggregate time series data on airline accident rates and profitability. These data suggest no decline in safety after deregulation, and provide weak evidence of an improvement in accident rates relative to the trend under regulation. Aggregate data may, however, mask important variations across carriers. To investigate the relationship of financial characteristics and accident rates at the firm level, I use data on 31 air carriers over the period 1955 through 1983. Accident rates for individual carriers are constructed, and differences in accident rates for different groups of carriers are analyzed. A statistical model of the determinants of individual accident rates is developed and estimated. This model relates profitability and other financial variables to accident rates, controlling for operating characteristics that also may affect accident probabilities. The results provide some evidence of possible profitability effects on safety.

1. INTRODUCTION

Airline safety has attracted tremendous attention in recent months. A record number of international airline passenger fatalities in 1985, as well as an increase in the domestic airline accident rate, focused attention on possible declines in airline safety as a consequence of economic deregulation. These issues have been debated in newspaper columns, network news broadcasts, business periodicals, and a host of other forums; see, for example, Feaver (1986), Gattuso (1986), Kahn and Kasper (1986), Magnuson (1987), Main (1985), Nance (1986), Nolan (1986), and Thayer (1986). Thayer's (1986) argument against deregulation is typical:

> ...competition unleashed by the economic deregulation of any industry forces many if not all companies to cheat and cut corners in ways that are dangerous to their customers, society at large and even themselves. This pattern, visible in any deregulated industry, is becoming increasingly obvious in the trucking and airline industries.

Despite substantial media attention, however, there has been relatively little scientific research on possible links between deregulation and safety conditions in the airline industry. Graham and Bowes (1979) investigate the link between firms' financial conditions and their accident rates, maintenance expenditures, and service complaints; Golbe (1986) analyzes the relation between accidents and profitability. Both studies use pre-deregulation data; neither finds much support for the argument that reduced profitability lowers airlines' safety performance. Advanced Technology (1986) analyzes bivariate correlations between financial measures and carriers' inspection ratings in the Federal Aviation Administration's (FAA) 1984 National Air

Transportation Inspection program. While the study finds some relation between financial indicators and inspection failures, its methodology has substantial shortcomings, particularly in that it fails to control for other factors that may affect inspection ratings. McKenzie and Shugart (1986) analyze the pattern of aggregate air fatalities and passenger-miles over the 1973 through 1984 period, and conclude that fatalities have not been adversely affected by indirect effects of deregulation on traffic or direct effects of deregulation on fatality rates. (See Fromm (1968) for an historical perspective on airline safety, and Oster and Zorn (1984) for an analysis of commuter air carrier safety.)

In this study, I investigate the relationship between accident rates and financial performance, controlling for operating characteristics of carriers that may affect their accident probabilities. The structure of the study is as follows. In section 2, I discuss economic models of firms' quality or safety choices, and assess their implications for the airline accident-financial performance relationship. Section 3 analyzes the aggregate accident data for all U.S. certificated route scheduled carriers over the 1955 through 1986 period. The use of a longer time period than earlier studies permits more precise estimates of both the accident trend rate under regulation and the effect of deregulation on the level or direction of that trend. These data also are used to estimate the effect of industry-wide profitability measures on accident rates; the data provide no evidence on aggregate profitability effects on safety. Section 4 explores the determinants of accident rates for individual carriers. Data are collected for 31 carriers over the 1955 through 1983 period, covering a broader range of carriers over a much longer time period than the data sets employed in earlier studies. Accident rates for individual carriers are constructed, and differences in accident rates for different groups of carriers are analyzed. Finally, a statistical model of the determinants of individual accident rates is estimated. The results provide weak evidence of possible profitability effects on safety. Section 5 contains a brief conclusion.

2. MODELS OF THE DETERMINANTS OF AIRLINE SAFETY DECISIONS

The effect of deregulation on safety levels is ambiguous on theoretical grounds. A number of private incentives encourage safety independent of direct government intervention. First, insurance companies base the premium rates for liability insurance on an assessment of risk. These companies have a strong incentive to monitor safety performance of carriers, and to increase premiums for firms that take on additional risk. This effect suggests that reducing safety expenditures may increase, not decrease, total costs once insurance premiums are taken into account. Second, firms have an important stake in maintaining a reputation for providing safe service in order to attract and retain business. Airlines that develop a reputation for being less safe will, other things equal, be likely to lose passengers to safer competitors. Some empirical research has analyzed the strength of these reputation incentives; see Barnett and Lofaso (1983) on passenger responses to the DC-10 crashes, Chalk (1985, 1986) on the effects of fatal accidents on aircraft manufacturers' profitability, and the work being done by Severin Borenstein and Martin Zimmerman on the profit effects of accidents for this conference. Third, employees have strong incentives to monitor safety, particularly when linked to maintenance of equipment or operating procedures. Pilots and flight attendants, because of their extensive exposure to an airline's flights, are at highest risk from any decline in air safety. These groups are likely to resist reductions in safety, or at minimum, to require compensating wage differentials for higher risk exposure. (The strength of this effect depends critically upon the alternative employment opportunities for these employees, for if their wages are above their opportunity wage, reduced safety may reduce their economic rents rather than leading to higher wages).

These private incentives do not guarantee the optimal level of safety, however. In particular, asymmetric information about safety may lead to less safety than is socially desirable. Asymmetric information is present when a firm has knowledge about its own level of safety that insurance firms, employees, and customers cannot or do not obtain. Under these circumstances, the firm may have an incentive to provide less safety than customers or employees desire. Models by Akerlof (1970), Klein and Leffler (1981), Shapiro (1982, 1983), Allen (1985) and numerous others examine the effects of asymmetric information on product quality or safety choices by firms. In these models, firms do not provide unambiguously lower safety, however; firms may choose to overprovide safety, depending on the values of various parameters. In Shapiro's (1982) model, for example, a firm may produce higher quality (safety) to improve its reputation.

In addition, none of these models establishes links between the level of profitability and safety choices. Yet this is precisely the relation that many critics of deregulation assume. One potential mechanism by which financial conditions may reduce safety provision by the firm is the possibility of bankruptcy. Because of limited liability laws, shareholders of a bankrupt firm have their "downside" risk limited to the amount of their equity holdings. This creates an asymmetry in shareholders' expected returns, with unlimited positive returns, but limited negative returns. Firms that are near insolvency might choose, for example, to reduce maintenance expenses and gamble on an increase in accidents in an effort to avoid bankruptcy. Bulow and Shoven (1978) and Golbe (1981) describe a model of the bankruptcy decision and its effect on stockholders' preferences for the firm's risk behavior. Even in this type of model, however, the attractiveness of increased risk through reductions in safety expenditures is ambiguous. If bankruptcy costs are high, firms will try to avoid actions that raise the risk of bankruptcy. For airlines, the tendency for failing carriers to exit the industry by mergers or acquisitions rather than liquidation of assets may provide another argument against reducing safety: if an airline increases its accident rate by reducing its safety expenditures, its value to potential acquirers is likely to be lower (the accidents will have eroded its goodwill or reputation). This could tend to counteract the incentives provided by limited liability. While more complex models of carriers' responses to financial distress may provide some predictions for the direction of financial influences on safety decisions, the issue is one that seems likely to be resolved only through empirical investigation. It is to this type of analysis that I now turn.

3. AGGREGATE DATA ON AIRLINE SAFETY

An analysis of the potential effect of deregulation on safety logically begins with a comparison of the safety performance of the industry before and after deregulation. If deregulation materially affected airlines' safety decisions, we should observe a change in the level of aggregate safety after 1978. In this section, I explore the behavior of industry-wide accident measures over time, and investigate the relationship between profitability and safety at the industry level. The rationale for using accident rates as a measure of safety is discussed in subsection 3.1; trends in aggregate accident data over the 1955-1986 period are explored in subsection 3.2; and the relationship between aggregate accidents and industry profitability is investigated in subsection 3.3.

3.1 Accident Rates as a Measure of Safety

While we cannot observe safety directly, a number of proxies for safety levels are available, including accidents, "incidents," FAA inspection results and citations, and levels of safety inputs such as maintenance. Each has particular advantages and disadvantages, and depending on the questions of interest, more than one of these measures might be incorporated in a statistical analysis. I follow a long tradition by focusing on accidents in the analysis below (see the data appendix for a description of what constitutes an accident). Accidents may be a noisy proxy for safety; because they are such low frequency events, it may be difficult to distinguish changes in the safety distribution without a long time series of observations. However, this measure has a number of advantages for the present analysis.

First, the number of air carrier accidents (fatal and nonfatal) reflect safety outcomes, which seems of most concern to passengers, and possibly to policy analysts: what is the probability that this flight will be involved in a fatal or non-fatal accident? FAA inspections and citations are more reflective of safety inputs, as are maintenance expenditures, training programs, and the like. Because the transformation of safety inputs into safety performance is itself uncertain and noisy, focusing on performance may provide a more reliable measure of the actual level of safety.

Second, accident reporting and detection is quite accurate, particularly for more serious accidents and larger airlines and relative to reporting of incidents and detection of safety violations through FAA inspections. Incident reporting is less consistent than accident reporting; judgment of what constitutes an incident may be more subjective, it is more difficult to detect non-reporting, and reporting may be sensitive to "campaigns" that highlight the issue in an attempt to improve reporting rates. Similarly, FAA inspection results and safety citations are unlikely to detect all violations, and the level of citations may depend critically upon the intensity of the FAA's enforcement activity, which is unlikely to be constant over time. For example, the FAA's recent record-setting fines of major trunk carriers may reflect lax safety procedures by the airlines, or they may reflect a decision by the FAA to signal its "seriousness" about enforcing safety violations (they also may reflect weaker enforcement, not necessarily better safety, in earlier periods). Reported accidents are likely to be more consistently measured through time.

Third, because this study focuses on measuring the effects of economic deregulation on safety, the selected safety measure should abstract from changes resulting from the Professional Air Traffic Controllers Organization (PATCO) strike in 1981 and the subsequent dismissal of the participating air traffic controllers. "Incidents," such as near misses, are likely to include a higher proportion of events that may be partially or wholly attributable to air traffic controller errors. While the number of accidents may be affected by air traffic control conditions, accidents seem somewhat less sensitive than an incidents index.

Finally, aggregate accident rates will yield fairly precise estimates of accident probabilities, particularly given the large number of flights in each year. U.S. major certificated air carriers ("part 121" carriers, which excludes commuter and air taxi operators) currently operate well over 5 million flights, logging 3 billion aircraft miles, per year. This substantial exposure of U.S. air carriers, combined with annual total accidents in the range of 15 to 25 during recent years, allows us to identify the probability of an accident with a great deal of precision. This feature of the aggregate statistics is frequently overlooked. When an individual carrier is small relative to the frequency of accidents, one more or one fewer accident may substantially change its accident rate (although this will average out across carriers). This sensitivity often is cited as an argument for disregarding accident statistics. Industry-wide total accident rates will have a much smaller variance, however, and therefore will provide a reasonably powerful test of changes through time. (Note that this argument will be less true for fatal accidents, which account for only 1 out of every 5 or more total accidents; the rate for fatal accidents will be less precisely estimated than will be the corresponding rate for total accidents).

Given these considerations, the analysis below uses accidents and accident rates per thousand departures to measure airline safety. I measure accidents by the number of accidents rather than passenger-based measures of accident incidence (such as passenger fatalities). This choice is dictated by two considerations. First, we have data on the number of passengers affected by accidents only for fatal accidents. Using passenger-based measures would limit the analysis to less than one-quarter of total accidents, throwing out much of the available information on safety performance. Second, one accident that kills all 200 people on board may have different implications about the safety of the system than 20 accidents with the same total fatalities. The decision to focus on the number of accidents implicitly judges the second scenario to reflect lower safety levels, all else equal.

3.2 Aggregate Accident Trends

Table 3.1 presents information on the total number of accidents, aircraft miles, revenue departures, and accident rates per 100,000 departures for U.S. certificated air carriers' scheduled passenger and cargo operations, from 1955 through 1986. Both fatal and nonfatal accidents are included in total accidents (column 1); fatal accidents are also tabulated separately in column 2. There is a steady decline in both fatal and nonfatal accidents over time, which is sustained after economic

TABLE 3.1

ACCIDENT RATES, U.S. CERTIFICATED AIR CARRIERS, SCHEDULED PASSENGER AND CARGO OPERATIONS (14 CFR 121 OPERATIONS)

Year	Accidents Total	Accidents Fatal	Miles millions	Depart. (100,000)	Total accidents/ 10^5 depart.	Fatal accidents/ 10^5 depart.
1955	61	11	779.93	32.76	1.86	.34
1956	70	7	869.31	35.03	2.00	.20
1957	73	7	976.17	37.69	1.94	.19
1958	67	8	972.99	36.33	1.84	.22
1959	78	14	1030.25	39.12	1.99	.36
1960	72	12	996.92	38.56	1.87	.31
1961	66	6	969.66	37.50	1.76	.16
1962	47	6	1009.68	36.60	1.28	.16
1963	54	6	1094.52	37.88	1.43	.16
1964	59	11	1189.14	39.54	1.49	.28
1965	65	8	1353.50	41.97	1.55	.19
1966	56	5	1482.27	43.73	1.28	.11
1967	54	8	1833.56	49.46	1.09	.16
1968	56	13	2146.04	53.00	1.06	.25
1969	51	8	2385.08	53.77	0.95	.15
1970	43	4	2417.55	51.00	0.84	.08
1971	43	7	2380.66	49.99	0.86	.14
1972	46	7	2347.96	49.66	0.93	.14
1973	36	8	2448.11	51.34	0.70	.16
1974	43	7	2258.14	47.26	0.91	.15
1975	29	2	2240.51	47.05	0.62	.04
1976	21	2	2320.00	48.33	0.43	.04
1977	19	3	2418.65	49.37	0.38	.06
1978	20	5	2520.17	50.16	0.40	.10
1979	23	4	2791.12	54.00	0.43	.07
1980	15	0	2816.30	53.53	0.28	.00
1981	25	4	2703.22	52.12	0.48	.08
1982	15	3	2698.93	49.64	0.30	.06
1983	22	4	2808.57	50.34	0.44	.08
1984	14	1	3113.57	54.48	0.26	.02
1985	18	4	3331.88	57.24	0.31	.07
1986	22	1	3723.00	64.35	0.34	.02

Sources: 1955-174 data from U.S. CAB, Handbook of Airline Statistics (various years). 1975-1986 data from U.S. NTSB (1986, 1987 press releases).

deregulation of the industry in 1978. The number of accidents declines even though the number of flights and aircraft miles increase sharply through time, implying even larger declines in the accident rates per 100,000 departures, as reported in columns 5 and 6 (and in accident rates per million miles, not shown). This improvement in safey is attributable primarily to the substantial improvements in aircraft and aviation technology over the last 40 years. These include the diffusion of radar technology; development of the jet aircraft (with enchanced power, range, and operating altitude); metallurgical and materials advances; the introduction and continued improvement of navigational and landing aids (such as automatic pilot, electronic glide slopes, ground proximity warning systems); more sophisticated simulators for pilot training, and the like.

Although accident rates continue to fall through the deregulated period, it is possible that deregulation has caused the rate of decline to deviate from its long-term trend. To estimate the effect of deregulation on accident trends, I model accidents as following a logarithmic decline over time and allow for the possibility that the accident trend shifts up or down with deregulation. This suggests an equation of the form:

$$\text{(3.1)} \qquad \ln(\text{ACCIDENT RATE}) = \beta_0 + \beta_1 * \text{TIME} + \beta_2 * \text{DEREG}$$

where TIME is a linear time trend and DEREG is a dummy variable equal to 1 for the years 1978-86, 0 otherwise. In 1980, fatal accidents are zero, and the logarithm of the fatal accident rate is undefined. I treat this by setting ln(fatal accidents) equal to zero and introducing a dummy variable, ZERODUM, equal to one when the number of accidents is zero and equal to zero otherwise (see Pakes and Griliches

(1980) and Hausman, Hall, and Griliches (1984) for a similar econometric treatment in a model of patents).

I estimate equation (3.1) by ordinary least squares regression, using three different measures of accident rates: the number of total accidents in a given year (TOTACC), the number of total accidents per 100,000 departures (TACCDEP), and the number of fatal accidents in a given year (FATACC). These results are reported in table 3.2. The decline in accidents through time is quite strong, with the number of total and fatal accidents declining by 4.4 (standard error, .6) to 5.0 (1.4) percent per year throughout the period, and the total accident rate per hundred thousand departures declining 6.4 (.6) percent per year. The equations for the two measures based on total accidents (columns 1 and 2) explain roughly 90 percent of the variance in accident rates over time. The third equation, for fatal accidents, explains 60 percent of the variation in fatal accidents over the period. Moreover, in all three equations, accident levels are below trend after deregulation, although this effect is statistically significant only for the total accident equation in column 1 (with total accidents roughly 30 percent below trend, as measured by $\exp(\beta_3) - 1$). This may suggest that improvements in safety technology or aircraft operation (such as cockpit management techniques adopted by many airlines in the 1980s) have advanced safety even faster than the long-term trend. The results for these and subsequent equations are qualitatively the same if the square root of accidents is used in place of the log of accidents (see appendix B for a discussion of the probability distribution of accidents and its implications for OLS regressions).

An alternative approach to evaluating pre- and post-deregulation performance is to estimate the accident equations over the regulated period only, and examine how well the regulation experience predicts accidents over the deregulated period. Figures 3.1 through 3.3 compare predicted accident rates based on this approach

TABLE 3.2

REGRESSION ANALYSIS OF AGGREGATE ACCIDENT RATES OVER TIME
1955-1986

Dependent Variable	ln(total accidents	ln(total accidents/ 10^5 depart)	ln(fatal accidents
Constant (β_0)	4.440 (.089)	0.907 (.079)	2.496 (.200)
TIME (β_1)	- .044 (.006)	- .064 (.006)	- .050 (.014)
DEREG (β_2)	- .262 (.133)	- .167 (.117)	- .051 (.305)
R-Square	.86	.93	.61
No. of Observations	32	32	32

Standard errors in parentheses.

Fig. 3.1

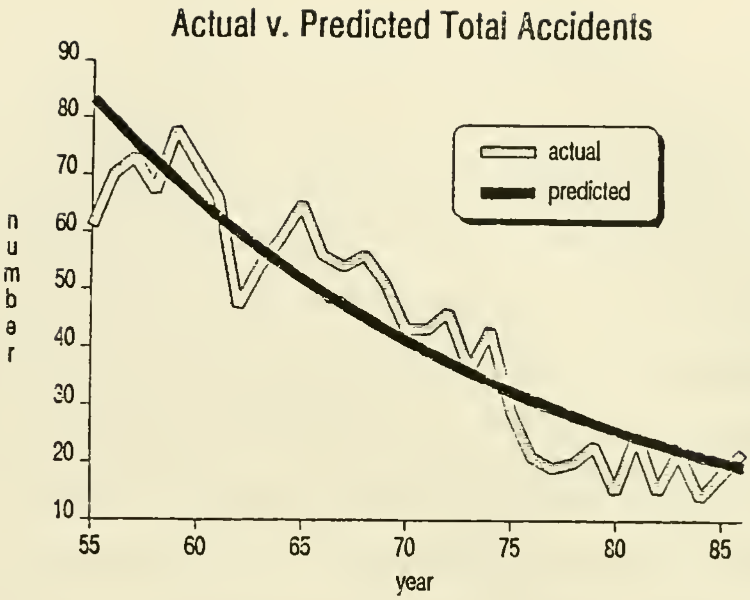


Fig. 3.2

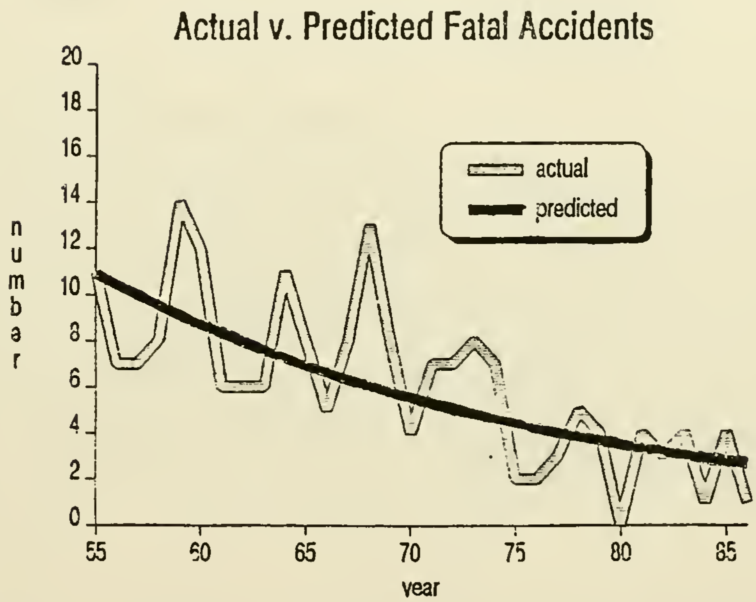
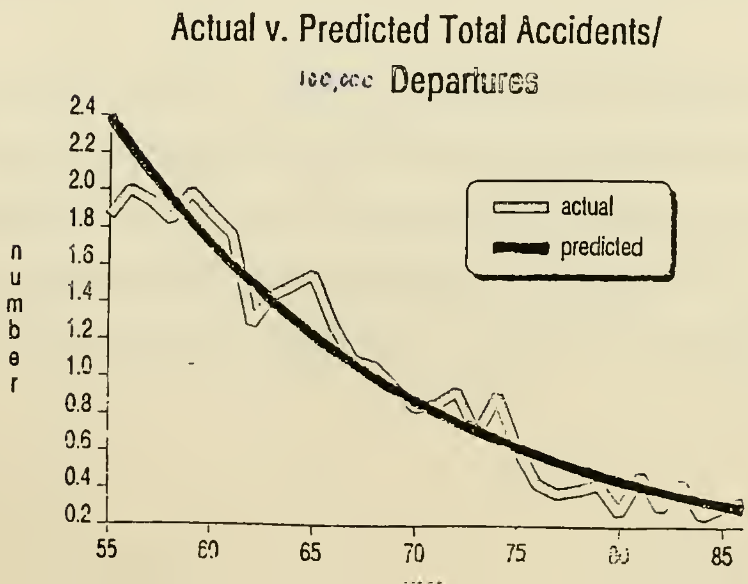


Fig. 3.3



with actual accident rates for the 1955 through 1985 period. The predicted rate curves are generated from equations of the form of (1), excluding DEREG and estimated over the 1955 through 1977 period. For rates based on total accidents (figures 3.1 and 3.2), the predicted levels conform reasonably closely to actual levels. Actual rates tend to be lower than predicted levels in the deregulation years, as expected from the negative DEREG estimates in the full time period results. Although fatal accident rates vary considerably from year to year, figure 3.3 suggests that the deregulation experience is consistent with predictions based on the regulatory era; there is no evidence that actual fatal accident rates are higher in the deregulated environment.

3.3 Aggregate Accidents and Industry Profitability

A final possibility to be explored with the aggregate data is the relationship between accidents and profitability at the industry level. The notion that lower profits induce airlines to shade on maintenance and other safety expenses may suggest that lower profit periods should be associated with higher accident rates. To test this hypothesis, I calculate the industry's average operating margin, OPMARG, defined as

$$\text{OPMARG} = 1 - (\text{operating expenses})/(\text{operating revenues})) \tag{3.2}$$

This is a measure of the industry's profit margin, calculated before interest, lease, and tax payments. Because OPMARG treats returns to all capital--debt, equity, and capital leases-- equivalently, it may be more comparable across carriers than are return on equity or net income measures. To insure that OPMARG is not contaminated by the costs of current accidents, and to reflect the assumption that profits are likely to influence accident rates with a lag (if at all), I use OPMARG from the preceeding period in the regression estimates (see section 4.3 for further discussion).

Table 3.3 presents the estimated coefficients for TIME, DEREG and OPMARG, using the three measures of accident rates that were used in table 3.2 as dependent variables. These equations are estimated over the 1956-1984 period, as the data series used to construct operating margin were unavailable after 1983. The results provide no support for the hypothesis that low profits reduce safety, at least in the aggregate. The TIME coefficients are essentially unchanged, and the DEREG coefficients are substantially similar to the earlier results. DEREG is now negative for only the accident level equations, although it is not statistically distinguishable from zero in any of the equations. In all three regressions, OPMARG has a counterintuitive positive sign, implying that <u>lower</u> profit margins correspond to <u>lower</u> accident rates. In all the equations, however, the standard errors on OPMARG are substantial, and the point estimate of the operating margin coefficient is statistically indistinguishable from zero. To test whether this is a function of pooling the regulated and deregulated samples into a single regression, I also estimated equations that allow OPMARG to differ pre- and post-deregulation. Unfortunately, the small number of post-1978 observations leads to enormous standard errors on the deregulation coefficients, which make it impossible to reject either the hypothesis that OPMARG has no effect on accidents in the deregulated period or the hypothesis that the coefficients are the same before and after deregulation. The results also are robust to using current, rather than lagged, operating margins. While the imprecision of the estimated OPMARG coefficients limit the power of these tests, there is no evidence in the aggregate accident data

TABLE 3.3

REGRESSION ANALYSIS OF AGGREGATE ACCIDENT RATES OVER TIME: THE INFLUENCE OF LAGGED PROFITABILITY

1956-1984

Dependent Variable:	ln(total accidents	ln(total accidents/ 10^5 depart)	ln(fatal accidents
Constant (β_0)	4.400	.920	2.302
	(.122)	(.115)	(.287)
TIME (β_1)	-.048	-.067	-.045
	(.007)	(.006)	(.016)
DEREG (β_2)	-.206	-.139	.038
	(.130)	(.122)	(.316)
OPERATING MARGIN (β_3) (lagged)	1.667	.689	2.318
	(1.079)	(1.015)	(2.541)
R-Square	.88	.93	.60
No. of Observations	29	29	29

Standard errors in parentheses.

that safety has deteriorated since deregulation, nor is there any evidence of negative effects of average profitability on the level of aggregate accidents.

3.4 Conclusions from the Aggregate Accident Analysis

This analysis of aggregate accident data for the major domestic air carriers provides no support for the view that safety levels have deteriorated in the aftermath of deregulation, nor does it indicate any correlation of aggregate profitability with aggregate safety. The results in section 3.2 are consistent with McKenzie and Shugart's (1986) findings that deregulation had no discernible effect on aggregate airline fatalities, either directly or through its effects on increased air passenger miles, based on data from 1973-1984. The results in section 3.3 are consistent with Golbe's (1986) time series analysis of the influence of profitability on aggregate accident rates. Using data from 1952-1972 and controlling for the number of departures and general economic conditions, Golbe finds that profitability tends to be associated with positive but statistically insignificant effects on accident rates.

While the aggregate data indicate no adverse change in accident rates after 1978, they provide a weak test of the hypothesis that deregulation reduced safety. Interfirm differences in accident rates permit more precise and more powerful tests of deregulation's effects on accidents. The next section analyzes firm-specific accident data.

4. ANALYSIS OF INDIVIDUAL AIR CARRIER ACCIDENT DATA

The argument that safety has declined since deregulation typically is based on an implicit link between the financial health or profitability of a carrier and its investment in safety. Advocates of this view claim that more profitable carriers choose to spend more on maintenance and safety-enhancing procedures, while low profit carriers "cut corners" on safety expenditures (Thayer (1986), Nance (1986)). Deregulation, they argue, reduces overall profits, and therefore safety. If this argument is correct, then safety should be linked to observable measures of firms' profitability or financial health. This section reports on a preliminary exploration of the determinants of accident rates for individual air carriers, focusing on the relationship of accident rates to firms' financial characteristics. (This work is presently being extended to apply the econometric models of count data developed in Hausman, Hall, and Griliches (1984) and Cameron and Trivedi (1986) to model airline accident rates.) If a profit-accident relationship exists, then the effect of deregulation on safety can be calculated from the effect of deregulation on firm characteristics. The analysis is restricted to major scheduled air carriers (described in further detail in the data section below), and covers the period 1955-1983.

The section is structured as follows: Section 4.1 describes the sample of air carriers and the data collected for each firm. Section 4.2 estimates the accident probabilities for each carrier across five-year time periods, and tests the similarity of accident rates through time and across different types of carriers (such as large versus small, high profit versus low profit). In section 4.3, I parameterize these accident probabilities, allowing them to vary continuously over time, and modelling them as a function of firms' operating and route characteristics, financial condition, and service experience. These results are used to test the effects of firms' financial condition on their safety records.

4.1 Individual Air Carrier Data

The data set used to evaluate individual air carrier safety performance consists of information on 31 scheduled air passenger carriers certificated by the CAB, over the period 1955 through 1983. The carriers include domestic and international trunks (12), local service carriers (6), intra-Alaskan and intra-Hawaiian airlines (5), territorial carriers (3), and intrastate carriers that expanded into interstate service after deregulation in 1979 (5). The sample carriers and their dates of data availability are listed in Table 4.1. Note that not all carriers are observed over the entire period. A number of carriers exit the industry, primarily through mergers or acquisitions, and data for intrastate carriers is not reported by the CAB prior to 1979.

The sample omits four major classes of air carriers: commuter airlines and air taxis, intrastate scheduled passenger air carriers, nonscheduled passenger carriers (charters), and cargo carriers. The first three groups were excluded primarily because of the unavailability or non-comparability of published data on their operations and financial conditions. Omission of commuter and nonscheduled air carriers also is supported on theoretical grounds: most of these carriers differ substantially from major scheduled air carriers in terms of their services, technology, and scale and scope of operations, suggesting that statistical inferences based on pooled samples may be quite misleading. The deletion of all-cargo carriers is dictated by our focus on air passenger safety.

A variety of operating and financial information was collected from CAB publications for each of the 31 sample carriers. The basic data for each carrier consists of system-wide information on accidents (TOTACC), revenue departures (DEPART), revenue aircraft miles (MILES), total maintenance expenses in (MAINT), total operating expenses (OPEXP), total operating revenues (OPREV). A number of

TABLE 4.1

SAMPLE AIR CARRIERS

Carrier	Basic Data Availability	COMPUSTAT Availability
Trunk Carriers:		
American Airlines	1955-1983	Y
Braniff Airways	1955-1981	
Continental Air Lines	1955-1983	Y
Delta Air Lines	1955-1983	Y
Eastern Air Lines	1955-1983	Y
National Airlines	1955-1979	
Northeast Airlines	1955-1971	
Northwest Airlines	1955-1983	Y
Pan American Airlines	1955-1983	Y
Trans World Airlines	1955-1983	
United Airlines	1955-1983	Y
Western Air Lines	1955-1983	Y
Local Service Carriers:		
Frontier Airlines	1955-1983	
Ozark Air Lines	1955-1983	Y
Piedmont Aviation	1955-1983	Y
Southern Airways	1955-1979	
Texas International	1955-1982	Y
USAir/Allegheny	1955-1983	Y
Intra-Alaska and Intra-Hawaiian:		
Alaska Airlines	1955-1983	Y
Aloha Airlines	1958-1974	
Hawaiian Airlines	1955-1983	Y
Northern Consolidated/Wien Consol.[a]	1955-1983	
Wien Air	1955-1967	
Territorial Carriers:		
Caribbean Airlines	1955-1972	
Pacific Northern	1955-1966	
Pan American-Grace	1955-1966	
Former Intrastate Carriers:		
Air California	1979-1983	
Air Florida	1979-1983	
Pacific Southwest Airlines	1979-1983	Y
Republic	1979-1983	
Southwest	1979-1983	Y

[a]Data reflects Northern Consolidated operations prior to its merger with Wien Air in 1968, and combined operations thereafter.

additional measures are constructed from these variables, including: exposure to international operations (DINTL, equal to one if the carrier has international operations, 0 otherwise), operating margins (OPMARG), real maintenance expenditures per mile (RMAINTPM, in millions of 1982 dollars), average stage length (AVSTAGE, in thousands of miles) and airline operating experience (measured in cumulative aircraft miles flown by the airline, EXPER, and the natural log of experience, LNEXPER), and TIME (a linear time trend). Several data series are missing information or are incompatible for part of the 1955-1983 time period (typically either the beginning or the end of the period); this may reduce the available sample size for any given application. Further details on the sources, construction, and availability of the data provided in Appendix A.

For a subsample of the carriers, detailed information on overall corporate capital structure, balance sheet, and income statements are available from COMPUSTAT for the 1967-1985 period. For these carriers, denoted by a Y in column 3 of table 4.1, a richer set of financial indicators could be constructed, including: return on equity (ROE), the common equity market to book ratio (MTB), the share of equity in total capitalization (EQRATIO, based on market, rather than book, values), and the current ratio (CURRENT, current assets/ current liabilities). These indicators reflect various aspects of a firm's profitability, solvency, and liquidity.

The statistical analysis focuses exclusively on total accidents, rather than fatal accidents. For individual carriers, fatal accidents are extremely rare events, even during the early part of the sample period. Given the scarcity of observations on fatal accidents, it will be quite difficult to identify the parameters of accident-operating characteristic relationships. Moreover, it is not clear that fatal accidents are *a priori* fundamentally different signals of safety than are nonfatal accidents, even though they are *ex post* substantially worse outcomes.

4.2 Accident Probabilities across Carrier Groups

Before estimating models of the relationship bewteen accidents and firms' operating characteristics, it is useful to ask whether different types of firms appear to have different accident probabilities. In this section, I first construct accident rates for individual carriers over five-year time periods, beginning with the 1955-1959 period and ending with the (four-year) 1980-1983 period. These accident rates vary substantially across carriers and through time. I next explore whether these variations are correlated with broad categories of operating or financial characteristics (such as high or low profits, large or small size).

Table 4.2 reports the accident rates per thousand departures for each sample carrier over each of the six time periods in the sample. Accident rates are calculated as N_{it}/D_{it}, the number of accidents for firm i during time period t divided by the total number of departures (in thousands) for firm i during period t. The last three rows of the table report the total accidents, total departures, and estimated accident rate for the entire sample of carriers in each period. The accident rate for the entire sample declines continuously through time, with the 1980-83 accident rate less than one-fifth of the initial accident rate in 1955-59. This reflects the trends observed in the aggregate data. Likelihood ratio tests of the equality of accident probabilities across time periods reject the hypotheses that sample aggregate accident rates in any two adjacent five-year periods are the same. The accident rates for individual carriers exhibit considerable variance, although some general patterns emerge: for example, the two international trunk carriers, PanAm and TWA, tend to have above average accident rates throughout the period,

TABLE 4.2

ACCIDENT PROBABILITIES BY CARRIER BY TIME PERIOD

Carrier	1955-59	1960-64	1965-69	1970-74	1975-79	1980-83
American	0.020	0.019	0.009	0.007	0.010	0.002
Braniff	0.011	0.008	0.009	0.006	0.005	0.003
Continental	0.012	0.012	0.013	0.005	0.008	0.013
Delta	0.009	0.014	0.011	0.011	0.006	0.002
Eastern	0.015	0.017	0.009	0.007	0.004	0.003
National	0.021	0.009	0.007	0.014	0.006	--
Northeast	0.026	0.011	0.018	0.000	--	--
Northwest	0.024	0.028	0.007	0.012	0.001	0.002
Pan American	0.038	0.026	0.026	0.018	0.009	0.012
Trans World	0.024	0.023	0.012	0.012	0.005	0.002
United	0.010	0.012	0.014	0.006	0.002	0.004
Western	0.018	0.007	0.007	0.003	0.006	--
Frontier	0.009	0.012	0.006	0.010	0.003	0.003
Ozark	0.011	0.009	0.006	0.003	0.000	0.007
Piedmont	0.009	0.011	0.008	0.007	0.001	0.001
Southern	0.004	0.011	0.004	0.005	0.002	--
Texas Int'l.	0.008	0.005	0.007	0.011	0.007	0.004
USAir	0.006	0.008	0.010	0.006	0.005	0.002
Alaska	0.059	0.093	0.012	0.014	0.010	0.000
Aloha	0.000	0.010	0.015	0.007	--	--
Hawaiian	0.000	0.007	0.005	0.000	0.000	0.006
North. Consol.	0.213	0.034	0.043	0.012	0.006	0.000
Wien Air	0.175	0.075	0.059	--	--	--
Caribbean Air	0.000	0.000	0.024	0.019	--	--
Pacific Northern	0.044	0.018	0.000	--	--	--
Pan Amer-Grace	0.000	0.000	0.000	--	--	--
Air Cal	--	--	--	--	0.000	0.009
Air Florida	--	--	--	--	0.000	0.015
PSA	--	--	--	--	0.000	0.000
Republic	--	--	--	--	0.000	0.001
Southwest	--	--	--	--	0.000	0.002
Total Accidents	241	223	220	182	94	55
Total Departures	13941	14988	19955	22237	21726	17272
Aggregate Accident Rate	0.017	0.015	0.011	0.008	0.004	0.003

as do the intra-Alaskan carriers, Alaska Airlines, Northern Consolidated/Wien Consolidated/Wien Air Alaska, and Wien Airlines (prior to its merger with Northern Consolidated). This illustrates the need for caution in interpreting the individual accident rates: higher rates may reflect differences in the inherent risk of areas served by particular carriers (such as potentially riskier conditions for international airports and Alaskan operations), rather than differences in carriers' safety per se.

To test whether groups of carriers with different characteristics exhibit different accident probabilities, I group carriers on the basis of four characteristics: type of operations (domestic trunk v. others), size (measured in passenger-miles), profitability (measured by operating margins) and maintenance expenditures (on a constant dollar per aircraft mile basis). For the size, profits, and maintenance tests, carriers are separated into "High" and "Low" groups, depending on whether their value of the relevant variable over the time period falls above or below a threshold value. The threshold is based on natural break points in the data, and is specific to each time period. This means that a carrier may be in the High group one period and the Low group the next period, and may be in different groups for different characteristics. The use of natural break points, when these occur, imply that the two groups (High and Low) may not be of equal size; the Low group in each period and for each characteristic tends to be slightly smaller than the High group, typically comprising 30 to 40 percent of the carriers. For the trunk/nontrunk test, domestic trunk carriers are considered the High group and all others are considered to be in the Low group.

I model the number of airline accidents per thousand departures as a Poisson random variable. The Poisson distribution is particularly suited to this type of problem, and has been employed widely in studies of accident probabilities (see Barnett, Abraham, and Schimmel (1979), Golbe (1986)). A detailed discussion of the distributional assumptions and estimation technique is contained in Appendix B. Given this distribution, the accident probability per 1000 departures, λ, can be estimated from the accident rate, N/D, for each group of carriers. From these accident probabilities, I construct likelihood ratio statistics to test the hypothesis that both High and Low groups are drawn from a common accident probability distribution. The results of these tests are reported in table 4.3. For each characteristic and each time period, table 4.3 reports a "+" if the accident probability of the High group significantly exceeds the accident probability of the Low group, a "-" if the accident probability of the High group is significantly below the accident probability of the Low group, and a "0" if the likelihood ratio test fails to reject the hypothesis that the two rates are equal. When the test rejects the equality hypothesis, the table also reports the ratio of the Low groups's accident probability to the High group's accident probability. It should be stressed that these tests reflect only bivariate correlations, and say nothing about causal relationships.

The results of these tests are mixed. The trunk/other distinction (column 1) does not appear to be associated with different accident probabilities; while the statistical equality of accident rates for these two groups is rejected in the first and last periods, the difference has opposite signs in the two periods. Thus, no clear pattern of differential accident rates is associated with this grouping. Similarly, size (passenger-miles, in column 4) does not appear to affect accident rates; in only one of the periods is there a significant difference between accident rates for the High and Low group. The evidence on operating margins is more difficult to interpret. Over the 1965-69 and 1980-83 period, High profit carriers have significantly lower accident rates than do Low profit carriers. This relationship is reversed, however, in the 1955-59 period, and there is no significant

TABLE 4.3

TESTS OF THE HOMOGENEITY OF ACCIDENT RATES ACROSS CARRIER GROUPS

	Characteristic on Which Carriers are Grouped			
Period	Domestic Trunks v. All Other Carriers	Operating Margin	Maintenance Expense/Mile	Passenger-Miles
1955-59	- (.021/.016)	+ (.016/.021)	+ (.010/.019)	0
1960-64	0	0	+ (.009/.017)	+ (.011/.016)
1965-69	0	- (.012/.009)	+ (.008/.013)	0
1970-74	0	0	+ (.007/.011)	0
1975-79	+ (.003/.005)	0	0	0
1980-83	0	- (.004/.002)	+ (.002/.004)	0

Legend:

+ denotes statistical rejection of equality of accident rates, when the High group's accident rate is estimated as higher than the Low group's accident rate.

- denotes rejection of equality of accident rates, when the High group's accident rate is estimated as lower than the Low group's accident rate.

0 denotes failure to reject the equality of accident rates.

Numbers in parentheses for tests that reject equality are (Low group's accident rate/High group's accident rate). Trunks are considered High for the trunk/nontrunk test.

difference in accident rates for the two groups during 1960-64 and 1970-79. The results may suggest the value of further exploration of profit-accident links; they do not provide very strong evidence on the existence or form of that relationship.

The results for maintenance expenditures per mile (column 3) stand in contrast to the results for other characteristics. In five of the six time periods, there is a significant difference in the accident rates of the High and Low carrier groups. While statistically significant and persistent through time, the direction of the relationship is surprising: Low maintenance expenditure carriers are associated with lower, not higher accident rates. In fact, accident rates for Low maintenance expenditure carriers are half to two-thirds the accident rates for High maintenance expenditure carriers. This result may be driven, at least in part, by the typically high maintenance expenditures of the international carriers, which we noted earlier also tended to have higher accident rates. This association, or the presence of some other factor that tends to raise both maintenance expenditures per mile and accident rates (such as aircraft age or fleet composition), may create a positive correlation between maintenance and accident rates. The regression analysis, by estimating the effect of maintenance holding other factors constant, may shed light on this result.

4.3 Regression Analysis of Individual Carriers' Accident Rates

In this section, I model the accident rates for individual carriers as a function of their traffic and financial characteristics. This permits us to estimate the correlation of a particular characteristic with accident rates, controlling for the level of other characteristics. The model should be interpreted as a reduced form, rather than as a structural model of the accident-generating process. The analysis is quite similar to studies by Graham and Bowes (1979), Golbe (1986), and Peter

Belenky (1986 unpublished memoranda), although the data and statistical techniques differ.

The basic specification of carrier i's accident rate in year t is:

$$\text{(4.1)}\quad \ln(TOTACC_{it}/DEPART_{it}) = \beta0 + \beta1{*}DINTL_{it} + \beta2{*}TIME_{it} + \beta3{*}AVSTAGE_{it} + \beta4{*}LNEXPER_{it} + \beta5{*}OPMARG_{it-1} + \beta6{*}RMAINTPM_{it}$$

where the variables are as defined in section 4.1 and appendix A. A log-linear specification is used to ensure that the estimated accident rates satisfy the non-negativity constraint.

I treat profitability (lagged OPMARG) and maintenance as exogenous variables from the standpoint of the accident generating process. Some empirical support for this treatment is provided by Golbe (1986), who finds that her data fail to reject the hypothesis of exogeneity for profitability measures. Using lagged profits reduces potential simultaneity problems: last period's profits should not be contaminated by costs that are incurred due to accidents this period (repair or replacement of aircraft, damage claims, higher insurance premiums, and the like). Lagged profits may also be appropriate since, even if low profit firms reduce safety investments or expenditures, the impact on accidents is unlikely to be immediate. The exogeneity of maintenance expenditures is less plausible, but is maintained due to the dearth of reasonable instruments for firm-level maintenance expenditures. Future work will explore the robustness of the results to the exogeneity assumption, and will attempt to develop instrumental variables estimators for the model.

The variables in equation (4.1) have the following interpretations and predictions: First, the accident rate, (TOTACC/DEPART), can be interpreted as an estimate of the underlying accident probability, λ_i. DINTL, a dummy variable for international operations, captures the effect of any higher risk associated with operations outside the U.S. To the extent that international operations are more risky, DINTL should have a positive coefficient. Its effect on accident rates is measured by a 100*(exp(ß1)-1) percent change in the expected accident rate if the carrier has international operations (the results below are qualitatively similar to those obtained using the proportion of international flights in place of this dummy variable). TIME allows for a logarithmic decline in accident rates over time, at the rate of ß2*100 percent per year. ß2 is expected to be negative. AVSTAGE reflects the effect of longer flights (holding constant the number of flights and all other right-hand side variables) on accident rates. Its expected sign is positive; the effect of an increase of 100 miles in the average stage length on accident rates is .1*100*ß3 percent. The log of cumulative flight experience (LNEXPER) is included to capture the notion that safety levels may rise with airline experience. The log-log specification of the relationship is taken from the literature on learning curves (see Joskow and Rose (1985) and the references cited therein). Given this rationale, the expected sign of ß4 is negative. A 1 percent change in experience is associated with a ß4*100 percent change in the accident rate. When experience is measured in levels (EXPER), the coefficient will imply a ß4*100 percent change in the accident rate for an additional million miles of cumulative airline experience. OPMARG, the operating margin, is a measure of carrier profitability. If the argument that lower profits induce lower levels of safety is correct, ß5 should be negative. A change in the operating margin from 0 to 10 percent (.10) will predict a .1*ß5*100 percent change in the accident rate. Finally, RMAINTPM, maintenance expenditures per aircraft mile in 1982 dollars, is included to control for the effects of variation in maintenance expenditures on accident rates. The standard financial health argument ("financially stressed carriers shade on maintenance, reducing safety") suggests a negative sign for this variable, although the results in section 4.2 from simple correlations between maintenance expenditures and accident rates found the opposite. A one dollar increase in maintenance expenditures per mile will be associated with a β_6*100 percent change in accident rates.

Variations on this basic equation include: measuring experience as the level of experience, EXPER; replacing the profit measure OPMARG with other profitability and financial health indicators from the COMPUSTAT data set, such as return on equity (ROE), the current ratio, the equity-to-total capital ratio, and the market-to-book ratio; replacing TIME with a series of time fixed effects (separate intercepts for each two or three year period), and measuring maintenance by total real expenditures.

Table 4.4 reports results for five variations of equation (4.1) for the period 1955 through 1982, for which complete data were available. These equations are estimated over 26 carriers, excluding the former intrastate carriers, for whom cumulative experience measures could not be calculated. The variations reported in table 4.4 are representative of a much broader range of specifications that have been estimated.

Column 1 is the basic specification in (4.1). In this equation, all variables except RMAINTPM have the expected signs, although a number of the point estimates are not precisely identified. The focus of the analysis is the influence of profitability, measured in these regressions by the operating margin and maintenance expenditures, on the accident rate. The coefficent on OPMARG is negative, implying that higher operating margins (profits) are associated with lower accident rates. A change in the operating margin from 0 to 10 percent is associated with a 3.16 (2.95) percent reduction in accident rates. However, the large standard error on the coefficient makes it difficult to determine the precise effect of OPMARG,

TABLE 4.4

REGRESSION ANALYSIS OF CARRIER ACCIDENT RATES

1955 - 1982

Variable	Basic Model 4.1	Variation 2	Variation 3	Variation 4	Variation 5
CONSTANT	-3.280	-2.934	-3.778	-2.982	-3.637
	(.126)	(.089)	(.068)	(.107)	(.067)
TIME	-.005	-.005	-.027	-.005	-.038
	(.005)	(.005)	(.004)	(.004)	(.004)
AVSTAGE	.666	.813	.634	.821	.218
	(.131)	(.126)	(.136)	(.121)	(.124)
LNEXPER	-.243	-.270	--	-.257	--
	(.026)	(.025)		(.030)	
EXPER	--	--	-.00017	--	--
			(.00003)		
OPMARG	-.316	-.422	−1.217	-.473	-.990
	(.295)	(.297)	(.311)	(.300)	(.319)
RMAINTPM	.175	--	--	--	--
	(.046)				
RMAINT	--	--	--	-.0003	--
				(.0003)	
DINTL	.047	-.026	-.237	--	-.256
	(.065)	(.007)	(.007)		(.067)
NOBS	612	612	612	612	612
SSR	197.3	202.1	225.8	201.9	241.5

Standard errors in parentheses
-- denotes variables omitted from regression

and the hypothesis that the true coefficient is zero could not be rejected at conventional levels of statistical significance. RMAINTPM is statistically significant, but of the wrong sign. The result is consistent, however, with the patterns observed in the carrier groupings in table 4.3. This suggests that we need better explanators for maintenance expenses, or better controls for omitted variables that may drive both accidents and maintenance. Given these problems with maintenance and the potential endogeneity of the variable, a number of the variations on equation 4.1 omit maintenance expenditures.

TIME has a very small negative effect on accident rates, corresponding to a half percent decline per year, and is statistically indistinguishable from zero. AVSTAGE has a positive effect on accidents: an increase in the average stage length from 500 to 1000 miles would raise the expected accident rate by 3.3 (.07) percent. For the 1980-83 sample aggregate accident rate of .003 in table 4.2, this would correspond to an increase in the accident rate from .003 to .0031. The coefficient on LNEXPER suggests a quite pronounced learning effect: doubling airline experience reduces the accident rate by 24.3 (2.6) percent. While this may in part reflect nonlinear time effects (as experience trends strongly through time), the persistence of this finding across a wide variety of specifications, including inclusion of individual year intercepts in place of TIME, suggests that experience effects are not purely time effects. Finally, DINTL is of the predicted sign, suggesting a 4.7 (6.5) percent higher accident rate for international carriers, but is statistically insiginificant.

The variations in columns 2 through 5 do not substantially affect the qualitative conclusions. OPMARG is negative in virtually every specification. Although its point estimate remains fairly imprecise, for specifications using the level of experience (such as regression (3)) and those omitting experience (such as regression (5)) we reject the hypothesis that the coefficient is zero at the 95 percent confidence level or better (using a two-tailed hypothesis test). For both regressions (3) and (5), the rejection of zero comes from a larger point estimate, not a smaller standard error. However, preliminary results for maximum likelihood estimation of accident probabilities following Hausman, Hall and Griliches (1984) suggest statistically significant negative estimates of the coefficient on OPMARG for almost all specifications, including those with LNEXPER (with point estimates in the range the results in (3) and (5)). These results all appear to suggest at least weak evidence of a profitability-accident relationship.

The level of maintenance expenditures, RMAINT, performs somewhat better than does RMAINTPM, although it remains statistically insignificant in most variations (only one of which is reported here). The coefficient on TIME is constant but imprecise in all the LNEXPER specifications, and is slightly larger in magnitude in the equations using EXPER or omitting experience. The effect of AVSTAGE is roughly constant throughout the variations, with the exception of the equations that omit experience, as represented by (5). LNEXPER is robust to most variations in specification. DINTL varies between positive and negative, insignificant and significant in the variations; it typically adds little to the explanatory power of the regressions.

To explore the profit-accident relationship further, I estimated equation 4.1 for various subsamples of firms and years. The first test explored the robustness of the relationship through time. The sample was divided into three time periods: 1955-1964, 1965-1974, and 1975-1982. The results for the first and third period are quite similar to the aggregate results for variations of the basic model; those for the middle time period differ primarily in the OPMARG coefficient. Table 4.5, columns 1 through 3, reports these results for the basic specification (4.1).

TABLE 4.5

SENSITIVITY TESTS OF BASIC REGRESSION RESULTS

VARIABLE	1955-1964	1965-1974	1975-1982	TRUNK	LOCAL SERVICE	TERRITORIAL
CONSTANT	-3.207	-2.625	-3.187	-3.612	-3.721	-2.160
	(.182)	(.333)	(.445)	(.237)	(.284)	(.169)
TIME	.011	- .015	- .015	- .021	- .003	.508
	(.019)	(.014)	(.015)	(.008)	(.017)	(.012)
AVSTAGE	.545	.883	.791	.786	.992	.697
	(.296)	(.209)	(.150)	(.156)	(.885)	(.220)
LNEXPER	- .276	- .319	- .239	- .230	- .200	- .282
	(.041)	(.046)	(.037)	(.050)	(.115)	(.092)
OPMARG	- .915	.031	- .749	- .485	.995	- .924
	(.510)	(.407)	(.694)	(.396)	(.619)	(.310)
RMAINTPM	.330	.019	- .098	.313	.011	.049
	(.090)	(.081)	(.063)	(.098)	(.204)	(.045)
DINTL	- .052	.088	.063	.128	--	.250
	(.114)	(.095)	(.090)	(.079)		(.086)
NOBS	231	232	149	305	159	148
SSR	71.361	63.208	18.360	83.956	16.374	20.193

Standard errors in parentheses

OPMARG has a large negative effect on accident rates during the early and late periods; this effect is statistically significant in the 1955-1964 period. OPMARG has essentially no effect during the 1965-74 period, although it is estimated with a quite large standard error. The coefficients of the remaining variables (except maintenance) exhibit considerable stability through time.

A second test explored whether the results were sensitive to pooling trunk, local service, and territorial/Alaskan/Hawaiian carriers. Variations of equation (4.1) were estimated for each of these groups separately, over the entire 1955-1982 period. The results were quite similar to the whole sample results for most specifications, with the exception of the local service regressions. Columns 4 through 6 in table 4.5 report the results for the basic specification (4.1) for trunk, local service, and territorial/Alaskan/Hawaiian carriers. OPMARG has a large negative effect for trunk and territorial carriers (statistically significant for the latter group). It is, however, estimated with a large positive coefficient for the local service carriers. The remaining coefficients (except maintenance) are relatively constant across groups.

Finally, I explored a richer set of financial measures for the subsample of firms with COMPUSTAT data. This restricted the sample to sixteen firms in the post-1967 period. For this subsample, the basic variations on (4.1) were estimated, as well as variations that included return on equity, current ratios, market-to-book ratios, and equity leverage ratios to measure profitability and financial health. For these regressions, none of the financial measures-- including OPMARG-- was statistically significant, and many were estimated with the wrong sign. Most of the other variables were broadly consistent with the full sample results.

These results provide mixed evidence on the robustness of the specification of the accident-generating process estimated here. The relationship seems in large part stable across numerous variations on the basic specification and across a variety of subsamples of the dataset. This provides suggestive evidence of a positive profits-safety relationship. However, there are enough aberrations to dictate further research into the robustness of the results. Future work will attempt to test the stability of equation (4.1) through time and the sensitivity of the results to variations in the functional form of the profitability specification. This effort is likely to involve collection of additional data to provide alternative measures of financial condition for the full sample of carriers, better indicators and instruments of maintenance expenditures, and a richer set of controls for accident rates.

5. CONCLUSION

The analysis provided in this study provides mixed implications for airline safety in a deregulated environment. On the one hand, the aggregate safety performance of the industry, as measured by both fatal and nonfatal accidents, is superb, and shows no sign of deterioration since deregulation. If there has been any change in accident performance relative to trends under regulation, it is a reduction in accident levels, not an increase. For three of the eight years under deregulation, for example, there have been no passenger fatalities-- as compared to no such years prior to deregulation. This provides strong evidence on the stability and soundness of the air safety system.

On the other hand, this study finds evidence that financial condition may be correlated with accident rates at the level of individual carriers. In the presence of controls for cumulative airline flight experience and other operating characteristics, higher operating margins appear to be correlated with lower accident rates. This finding, if it proves to be robust, suggests grounds for possible concern. In particular, to the extent that the deregulated airline market involves less insulation of carriers from the effects of market forces, more intense scrutiny of the safety practices and performance of financially marginal carriers may be desirable. Note that the results do not, however, imply that deregulation is undesirable, even on safety grounds. The enormous social benefits of deregulation (see Morrison and Winston (1986)) and the maintenance of an outstanding air safety record both appear achievable.

APPENDIX A

DATA DESCRIPTION AND SOURCES

1. Accident data: An accident is defined by the National Transportation Safety Board (NTSB) as "an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all persons have disembarked, in which any person suffers death or serious injury as a result of being in or upon the aircraft or by direct contact with the aircraft or anything attached thereto, or in which the aircraft receives substantial damage" (U.S. Department of Transportation, 1980, p.18).

Individual air carrier accident data are from the U.S. Civil Aeronautics Board (CAB), Resume of Accidents, U.S. Air Carriers, Rotorcraft and Large General Aviation Aircraft (annual, 1953-1959); U.S. CAB, Statistical Review and Briefs of U.S. Air Carrier Accidents (annual, 1960-1965); U.S. NTSB, Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations (succeeds the CAB accident publications; various years, 1966-1982); the U.S. NTSB, Preliminary Analysis of Aircraft Accident Data, U.S. Civil Aviation (various years, 1979-82), and the NTSB Accident Briefs (unpublished computer printout, for 1983-1984). These data were available from 1954 through 1984.

2. Traffic data: Annual airline system revenue departures (DEPART) in thousands and aircraft miles (MILES) in millions are from the U.S. CAB, Air Carrier Traffic Statistics (various issues, 1954-1983). Average stage length (AVSTAGE) is computed as MILES/DEPART, and is measured in thousands of miles.

3. Financial data: Annual airline system operating revenues and operating expenses are from the U.S. CAB, Air Carrier Financial Statistics (various issues, 1954-1982). All dollar-denominated variables are in millions of dollars. The system operating ratio (OPRAT) is calculated as (operating expenses)/(operating revenues). The operating margin, OPMARG, is 1-OPRAT. Real net income (RINC) is calculated as the difference between operating revenues and operating expenses, and is transformed to 1982 constant dollars using the implicit GNP deflator.

Capital structure variables are calculated from COMPUSTAT data, and reflect financial data for the entire corporation, not just air carrier operations. CURRENT is the current ratio, calculated as current assets/current liabilities. MKTBOOK is the ratio of market value of common equity to book value of common equity. The return on equity (ROE) is calculated as net income before extraordinary items and discontinued operations divided by the book value of common and preferred equity. The equity ratio (EQRATIO) is computed as (market value of common equity)/(market value of common equity + redemption value of preferred equity + book value of long-term debt). The COMPUSTAT data are available from 1967 through 1985 for a sub-sample of airline carriers.

4. Maintenance: Maintenance expenditures are from the U.S. CAB, Air Carrier Financial Statistics (various issues, 1956-1982). Because of changes in the CAB's financial statistics reports, these data are available only from 1956 on. RMAINT1 is real maintenance expenditures in millions of 1982 dollars, where nominal expenditures are escalated using the implicit GNP deflator. RMAINT2 divides nominal maintenance expenditures by an average mechanics wage series to obtain a deflated maintenance cost series. RMAINTPM is real maintenance expenditures per mile, calculated as RMAINT1 divided by the number of aircraft miles.

The mechanics wage series is constructed from two sources. For 1955-60, the mechanics wage is the mid-point of the hourly wage range for Grade 5 mechanics at Lockheed-California, obtained from: U.S. Department of Labor, Bureau of Labor Statistics, Wage Chronology: Lockheed-California Company [Division of Lockheed Aircraft Corp.] and Machinists Union, March 1937-October 1977, Bulletin 1904, 1976. For 1961-1983, the wage is the motor vehicle mechanics average wage from the U.S. Department of Labor, Bureau of Labor Statistics, Handbook of Labor Statistics (1975-Reference Edition, Bulletin 1865, Table 109, p. 285 for 1961-74; Bulletin 2217, June 1985, Table 96, p. 277 for 1975-83).

5. Experience: Airline experience (EXPER) in year t is calculated as the cumulative MILES flown, from 1954 through year t.

APPENDIX B

A PROBABILITY MODEL FOR ACCIDENTS

A natural stochastic specification for the number of air carrier accidents is based on the Poisson probability distribution. The Poisson distribution recognizes the infrequent and discrete natures of accidents, and has been applied extensively as a model of accident probabilities in a wide variety of contexts, including air carrier accidents (Barnett, Abraham, and Schimmel (1979), Golbe (1986)). For our purposes, is is most plausible to specify the number of accidents in a year as a function of an (unknown) accident rate per thousand departures and the number of departures (in thousands), rather than to specify an accident rate per year. (This is equivalent to assuming that each flight has some probability, p, of being involved in an accident, and that the number of flights is large, which takes advantage of the binomial distribution's convergence to the Poisson in the limit.)

Using the Poisson distribution, and denoting firm i's expected number of accidents as λ_i, its number of departures (in thousands) in a year as D_i, and its number of accidents in a year as n_i, we can express the probability that firm i experiences n_i accidents during the year as:

(B.1) $$Pr\ (n = n_i) = [\exp(-\lambda_i D_i)](\lambda_i D_i)^n / n!$$

The maximum likelihood estimator (MLE) for the accident rate λ_i is $\lambda_i = n_i/D_i$.

The analysis in section 4.2 relies on this simple parameterization of carrier's accident probabilities to investigate whether different types of air carriers have different underlying accident probabilities. To illustrate this technique, consider a test of the equality of accident rates for domestic trunk carriers and all other carriers. Let N_1 be the total number of accidents and D_1 be the total number of departures for group 1 (domestic trunk carriers), and let N_2 and D_2 be the corresponding totals for group 2 (all other carriers). We will impose the assumption of homogeneity within each group ($\lambda_i = \lambda_1$ for all i belonging to group 1; $\lambda_j = \lambda_2$ for all j belonging to group 2), and test for homogeneity across groups: $\lambda_1 = \lambda_2 = \lambda_0$. The MLE for λ_1 and λ_2 are $\hat{\lambda}_1 = N_1/D_1$ and $\hat{\lambda}_2 = N_2/D_2$. The MLE for λ_0 is $\lambda_0 = (N_1 + N_2)/(D_1 + D_2)$. To test for homogeneity, we construct the ratio of the likelihood under the null hypothesis that groups 1 and 2 are drawn from the same probability distribution to the likelihood under the alternative hypothesis that $\lambda_1 = \lambda_2$. This likelihood ratio is:

(B.2) $$LR = \frac{\lambda_0^{(N_1+N_2)}\exp(-\lambda_0(D_1 + D_2))}{\lambda_1^{N_1}\lambda_2^{N_2} \exp(-\lambda_1 D_1 - \lambda_2 D_2)}$$

Substituting in the maximum likelihood estimates of λ_0, λ_1, and λ_2 and taking the log of LR yields a log-likelihood of:

(B.3) $$\begin{aligned} \text{LogLR} = {} & (N_1 + N_2)\ln((N_1 + N_2)/(D_1 + D_2)) - \\ & N_1\ln(N/D_1) - N_2\ln(N_2/D_2) \end{aligned}$$

The test statistic -2LogLR is distributed as a chi-square(1) random variable.

In section 4.3 we relax the assumption that all carriers within a particular group have identical accident rates. We parameterize λ_1 as a function of a carrier's operating and financial characteristics. Denote these characteristics as the vector X_i. We parameterize the accident rate per thousand flights as $\lambda_i = \exp(X_i\beta)$. This parameterization ensures that the estimated accident rates satisfy the non-negativity restriction on λ (i.e., the expected number of accidents must be greater than or equal to zero). This parameterization of the accident rate is estimated by ordinary least squares (OLS) regression of the form:

$$(B.4) \qquad \ln(N_i/D_i) = X_i\beta$$

This is a simple linear equation in the log of the observed accident rate per thousand flights. The elements of the estimated coefficient vector β_{ols} have the interpretation that a one unit change in the corresponding variable in X will lead to a β_{ols}*100 percent change in the accident probability. Note, however, that if accidents are distributed as Poisson, OLS will no longer be an efficient estimator. In particular, the mean of a Poisson distribution (λ_i) is equal to its variance, which implies heteroscedasticity in equation (B.4). The standard errors calculated under the OLS assumptions will be inconsistent estimates of the true standard errors. One solution to this heteroscedasticity is to use the square root of the number of accidents as the dependent variable, which will have a constant variance under the Poisson assumption (see Golbe (1986)). This will not, however, ensure satisfaction of the non-negativity restriction on λ. I therefore maintain the log-linear specification of (B.4). The problem of heteroscedasticity will be addressed in a later version of this paper. In addition, maximum likelihood estimates of the parameters of the accident generating process, along the lines developed in Hausman, Hall and Griliches (1984) and Cameron and Trivedi (1986), are currently being explored. These techniques explicitly treat the heteroscedasticity of the Poisson process.

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