Effects of Snowfalls on Motor Vehicle Collisions, Injuries, and Fatalities

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Effects of Snowfalls on Motor Vehicle Collisions, Injuries, and Fatalities

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Objectives. We estimated the effects of snowfalls on US traffic crash rates between 1975 and 2000.

Methods. We linked all recorded fatal crashes (1.4 million) for the 48 contiguous states from 1975 through 2000 to daily state weather data. For a subsample including 17 states during the 1990s, we also linked all recorded property-damage-only crashes (22.9 million) and nonfatal-injury crashes (13.5 million) to daily weather data. Employing negative binomial regressions, we investigated the effects of snowfall on crash counts. Fixed effects and other controls were included to address potential confounders.

Results. Snow days had fewer fatal crashes than dry days (incidence rate ratio [IRR] = 0.93; 95% confidence interval [CI] = 0.90, 0.97), but more nonfatal-injury crashes (IRR = 1.23; 95% CI = 1.18, 1.29) and property-damage-only crashes (IRR = 1.45; 95% CI = 1.38, 1.52). The first snowy day of the year was substantially more dangerous than other snow days in terms of fatalities (IRR = 1.14; 95% CI = 1.08, 1.21), particularly for elderly drivers (IRR = 1.34; 95% CI = 1.23, 1.50).

Conclusions. The toll of snow-related crashes is substantial. Our results may help estimate the potential benefits of safety innovations currently proposed by meteorology and traffic safety experts. (*Am J Public Health.* 2005;95:120–124. doi: 10.2105/AJPH.2004.048926)

Poor weather-related driving conditions are associated with 7000 fatalities, 800 000 injuries, and more than 1.5 million vehicular crashes annually in the United States.[1] Adverse weather is present in 28% of total crashes and nearly 20% of highway fatalities.[2] Analysts estimate the economic toll of weather-related crashes at $42 billion.[3] Understanding the effects of adverse weather on motor vehicle crashes matters because experts have identified a number of communications and engineering innovations (largely technologies to collect and communicate real-time road condition information, such as sensors and dynamic message signs) that could significantly reduce the crash and injury rates, but at a potentially substantial cost.[1,2]

Previous studies have associated precipitation with markedly increased crash rates.[4–7] Recent work also shows that the risk posed by precipitation rises dramatically with the time since last precipitation.[4] Less well studied to date are the effects of a specific form of precipitation, snowfall.

Crash counts are not inevitably higher in snowy weather than in dry weather. On the one hand, snow makes driving more dangerous, by reducing tire adherence and impairing visibility. On the other hand, experienced drivers typically drive more slowly and carefully in snowy weather, and many people avoid or postpone unnecessary travel. Perhaps as a reflection of these offsetting factors, the handful of published studies addressing the crash consequences of snow has produced some conflicting results. The weight of the evidence suggests that less severe crashes (e.g., those producing only property damage) increase during snows, while more severe crashes (those resulting in fatalities) decrease.

Significantly increased crash rates have been documented in snowy months in Canada,[8] on snowy days in the United Kingdom,[9] and during snowstorms in Iowa.[10] Perry and Symons[9] found increased rates of crashes involving injuries and fatalities on snowy days in the United Kingdom, but Brown and Baass[11] noted fewer crashes involving injuries in the winter months in Canada, as did Fridstrom et al.[7] in snowy months in Denmark and Finland. Eisenberg[4] found decreased rates of fatal crashes on snowy days in the United States, a finding echoed in analysis of winter months in Canada[11] and snowy months in Scandinavia.[7]

To date, only 2 previous studies have examined the effects of the first snowfall of the season. Defining first snowfall as the first snow in a month following a month without snow, Fridstrom and Ingebrigtsen[12] found significant increases in both injury and fatal crashes in Norway. Subsequently, however, research by Fridstrom and colleagues[7] produced mixed findings: injury crashes rose significantly during the winter's first month with snow (compared with other months with snow) in Denmark but not in either Finland or Norway. Fatality rates were no different in the first snowy month than in other snowy months.

We present findings from the first detailed analysis of the impact of snowfall on crash rates by severity level (property damage only, injury, and fatal) in the entire United States (excluding Hawaii, Alaska, and the District of Columbia), using a data set combining daily data on traffic crashes and snowfall for the period 1975 through 2000. Of special interest are the effects of first snowfalls of the season, which might be expected to affect crashes and their outcomes differently from later snowfalls. Many people may be unprepared to avoid driving when the first snowfall occurs each year; others may not adapt driving procedures, such as reducing speed and braking earlier, as completely as they will later in the snow season. We also present the first analysis of the differential effects of snowfall on drivers of different ages.

METHODS

We merged publicly available databases on traffic crashes and snowfall measures, as described in this section. The sample included all 48 contiguous states for the years 1975 through 2000. The unit of analysis was a unique state–day combination, which yielded 455 952 potential observations. Missing weather data reduced the sample to 429 253 state-days. Whether or not a day had missing weather data appears to be unrelated to snowfall. Days with missing data were spread evenly across the calendar year; no month accounted for less than 7.9%, or more than 9.0%, of the missing observations.

The outcome measure was the number of traffic crashes. Traffic crashes were categorized into 3 levels of severity: fatal, nonfatal injury, and property damage only. Fatal crash counts were taken from the Fatal Accident Reporting System,[13] a database of fatal crashes in the United States maintained by the National Highway Traffic Safety Administration (NHTSA) since 1975. A total of 1.4 million fatal crashes were included in our analysis. Nonfatal-injury and property-damage-only crash counts were available through the NHTSA's State Data System[14] for a subsample of 17 states during the 1990s, which yielded 59 820 state-days corresponding to 13.5 million nonfatal-injury crashes and 22.9 million property-damage-only crashes.

Snowfall, in centimeters, was derived from the National Climatic Data Center's Cooperative Summary of the Day, TD 3200,[15] a database containing historical daily weather measures from over 20 000 weather stations in the United States. Weather station data were averaged, weighted by the weather division areas they represent, to create state-level measures. Nonsnow precipitation (rain or sleet) was also included as a control variable in the analysis, leaving dry days as the baseline day. We defined rain days, including sleet, as days with some precipitation and no more than 0.5 cm of snow. Snow days were defined as days with at least 0.5 cm of snow. We defined a first snow day as the first day (in a state) with at least 0.5 cm of snow after a period of 100 days during which there were no days with 0.5 cm of snow.

Bivariate analysis was conducted with χ^2 tests comparing traffic crash rates across different categories (dry days, rain days, nonfirst snow days, first snow days). Multivariate analysis was conducted by negative binomial regression, a generalized version of the Poisson regression. Previous studies of traffic crashes indicated that this specification was warranted.[7] The negative binomial regression can be expressed in terms of the Poisson and Gamma distributions in the following way:

$$(1) \qquad C_{st} \sim Poisson(\mu_{st}),$$
$$\text{where} \quad \mu_{st} = e^{(X_{st}\beta + offset_{st} + u_{st})}$$
$$\text{and} \quad e^{u_{st}} \sim Gamma(\frac{1}{\alpha}, \frac{1}{\alpha})$$

C_{st} refers to the crash count for a given observation, for state *s* and time *t*. X_{st} is a vector including the independent variables of interest: indicators of snowfall and nonsnow precipitation. In addition, X_{st} includes 3 vectors of dummy variables representing fixed effects for each state, year, and month. These fixed effects accounted for general trends across geographic areas and time, as well as seasonal effects. Although weather variables are as exogenous as one can hope for in an observational analysis, the inclusion of fixed effects served as an additional check against spurious relationships.[16]

$Offset_{st}$ refers to the amount of exposure for a given observation; that is, the denominator used to refer to crash rates. An estimate of vehicle miles traveled for each state-year, published by the Federal Highway Administration,[17] was used for this purpose. Since this measure could not account for day-to-day fluctuations in vehicle miles traveled within state-years, the estimated relationships between snowfall and crashes may be mediated in part by (unobserved) reduction in traffic volume. We elaborate on this idea in the Discussion section below. We calculated standard errors using a Huber–White estimator of variance clustered by state. Some additional technical issues related to these data and methods are detailed in an earlier study.[4]

RESULTS

Table 1 presents crash rates, as proportions of rates on dry days: rain days, nonfirst snow days, and first snow days. On nonfirst snow days, which account for 97% of total snow days, nonfatal-injury crashes increased substantially (incidence rate ratio [IRR]=1.24; 95% confidence interval [CI]=1.22, 1.26), as did property-damage-only crashes (IRR=1.78; 95% CI=1.74, 1.78). Fatal crashes, by contrast, decreased (IRR=0.84; 95% CI=0.83, 0.85). First snow days appeared to be significantly more dangerous than other snow days, particularly for fatal crashes (IRR=1.30; 95% CI=1.21, 1.38). One can compare first snow days with dry days by simply multiplying the 2 relative risks just given. Analyses using a variety of cutoff points other than 0.5 cm of snow to define a "snow day" (0.25 cm, 0.75 cm, 1.0 cm, 1.5 cm, 2.0 cm) yielded nearly identical findings (not shown here).

The results shown in Table 1 do not necessarily represent true causal effects of weather conditions on traffic crashes. There are a variety of potential confounding factors. For example, states with more snow may have safer or less safe drivers, on average, or safer or less safe road infrastructure. Also, traffic volume varies seasonally, peaking during the summer months when snow is extremely rare. In estimating first snowfall effects, another possible confounder arises: first snowfalls may be more likely to follow dry periods, which have been shown to increase the risk of subsequent precipitation.[4]

TABLE 1—Wet Day Crash Rates Relative to Dry Day Crash Rates

	Fatal Crashes, IRR (95% CI)	Nonfatal-Injury Crashes, IRR (95% CI)	Property-Damage-Only Crashes, IRR (95% CI)
Dry days	1.00	1.00	1.00
Rain days relative to dry days	1.06 (1.06, 1.07)	1.19 (1.18, 1.19)	1.15 (1.14, 1.16)
Nonfirst snow days relative to dry days	0.84 (0.83, 0.85)	1.24 (1.22, 1.26)	1.78 (1.74, 1.82)
First snow days relative to nonfirst snow days	1.30 (1.21, 1.38)	1.13 (1.05, 1.21)	1.00 (0.90, 1.10)

Note. IRR = incidence rate ratio; CI = confidence interval.

TABLE 2—Snowy Day Crash Rates, Adjusted for Potential Confounders

	Fatal Crashes, IRR (95% CI)	Nonfatal-Injury Crashes, IRR (95% CI)	Property-Damage-Only Crashes, IRR (95% CI)
Nonfirst snow days relative to dry days	0.93 (0.90, 0.97)	1.23 (1.18, 1.29)	1.45 (1.38, 1.52)
First snow days relative to nonfirst snow days	1.14 (1.08, 1.21)	1.04 (0.98, 1.11)	1.01 (0.95, 1.08)

Note. IRR = incidence rate ratio; CI = confidence interval. Potential confounding factors that were adjusted for (in negative binomial regressions) include the following: (1) time since last precipitation; (2) rainfall on "snow days"; (3) state, year, and month fixed effects.

We controlled for such potential confounders in our multivariate analysis. State, year, and month fixed effects account for possibilities such as snowy states' having less safe drivers on average, by accounting for general differences across states, years, and months (as described in the Methods section). We also included in the regression a control variable equal to the number of days since the most recent precipitation event.

The regression results presented in Table 2 indicate a pattern of snowfall effects similar to those in the unadjusted differences. Fatal crashes were 0.93 times as frequent on nonfirst snow days (95% CI=0.90, 0.97) compared with dry days, whereas nonfatal crashes were substantially *more* frequent (for nonfatal-injury crashes, IRR=1.23; 95% CI=1.18, 1.29; for property-damage-only crashes, IRR=1.45; 95% CI=1.38, 1.52). First snow days had 1.14 times more fatal crashes (95% CI=1.08, 1.21) than nonfirst snow days. For nonfatal-injury crashes, the first snow differential was less, and was not significant ($P=.05$).

Examining the first snowfall fatality differential in more detail, we estimated the effects of first, second, and third snowfalls. The results suggested a tapering effect: compared with later snowfalls, first snowfall increased the fatality rate by a factor of 1.17 (95% CI= 1.11, 1.24), second snowfall by 1.11 (95% CI=1.05, 1.17), and third snowfall by 1.10 (95% CI=1.04, 1.17).

We also considered the role of snow intensity. First snowfalls may appear to be more dangerous simply because their intensity is different on average. We addressed this possibility by controlling for snowfall intensity with a set of categorical variables, where "light" is defined as 0 to 1 cm, "medium" as 1 to 4 cm, "heavy" as 4 to 8 cm, and "very heavy" as more than 8 cm. Regression results indicated that first snowfalls, when compared with nonfirst snowfalls of comparable intensity, were associated with more fatal crashes for all snow intensity levels. The first snow effect for light snow days was 1.13 (95% CI=1.06, 1.21), for medium snow days 1.19 (95% CI=1.10, 1.29), for heavy snow days 1.11 (95% CI=0.92, 1.35), and for very heavy snow days 1.25 (95% CI=0.93, 1.69). The estimates for heavy and very heavy snow days were less precise because these events are much less common.

Figure 1 indicates that effects of snowfall on crashes varied by age group. The numbers shown are estimated in regressions comparable to those reported in Table 2. By far, elderly drivers (older than 65 y) exhibited the most vulnerability to the first snowfall effect: a 1.34 (95% CI=1.23, 1.50) incidence rate ratio compared with nonfirst snowfalls. The added danger of first snows for drivers aged between 30 and 50 years and drivers aged younger than 18 years were factors of 1.12 (95% CI=1.04, 1.19) and 1.11 (95% CI=0.94, 1.34), respectively. As for nonfirst snowfalls, drivers aged between 30 and 50 years appeared most susceptible, probably because they were least likely to avoid driving in snowy conditions (see the lightly shaded part of the bars).

DISCUSSION

This analysis demonstrates that, although snowfalls generally increase crash rates as one might expect, specific outcomes might not be anticipated: while both nonfatal-injury and property-damage-only crashes increase significantly when it snows, fatal crashes decline. Compared with nonfirst snowfalls, the first snow of the season significantly increases the fatality rate. The most dramatic fatality consequence of driving in first snowfalls occurs for the elderly (older than 65). In nonfirst snowfalls, however, elderly and young (aged younger than 18) drivers actually experience reduced fatality rates (relative to those on dry days), whereas those aged 30 to 50 years experience a slightly increased rate. This difference across age groups may result from reduced driving for the first 2 groups during snow. Driving for them may be more discretionary than for nonelderly adults who have to get to work regardless of the weather, and typically drive to do so.

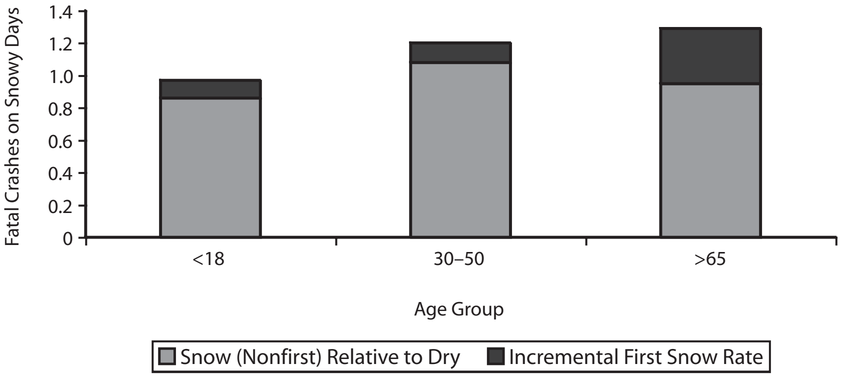

FIGURE 1—Rates of fatal crashes on snowy days compared with dry days, by age group and conditions.

The greatly increased fatality rate for the elderly during first snowfalls is especially troubling. Either they do not reduce their driving as much during first snowfalls as during subsequent snows, or they do not adjust their driving behavior in response to the beginning of the snow season as quickly as do the nonelderly. Our data do not allow us to distinguish the relative contributions of these possibilities, as traffic volume data are not available by age (nor on a daily basis, as discussed 2 paragraphs below).

Our results do suggest one clear behavioral pattern for drivers overall. Compared with dry days, snow days result in a reduction in the most serious crash outcome, fatalities, but an increase in less serious outcomes. This suggests that drivers adjust their driving behavior enough to reduce the severity of outcomes when collisions occur—by driving more slowly, for example—but not enough to reduce (or even maintain) the frequency of collisions.

Traffic volume data are not available on a daily basis by state, so we cannot directly control for the reduced exposure associated with snowy weather. In small-scale studies, however, traffic volume has been shown to decrease anywhere from 7% to 56% in snowy conditions.[10,18] If a 29% reduction in traffic (the average estimated by Knapp and colleagues in Iowa[10]) applies to our sample, we would multiply the results shown in Table 1 by a factor of 1.4 [i.e., 1/(1 – 0.29)] to get the increased risk faced by an average person on the road in snowy conditions. In other words, persons on the road during snowfalls experience a fatality risk 18% higher than on dry days (0.84 × 1.4=1.18). Their injury risk would rise by nearly three quarters (1.24 × 1.4=1.74) and property-damage-only crash risk would increase about 150% (1.78 × 1.4=2.49). Viewed from this perspective, snow appears to pose a truly substantial risk for drivers on the road. Note that if we wish to be conservative and consider the full range of reduced traffic volume estimates (7% to 56%), we would multiply the numbers in Table 1 by a factor of anywhere from 1.08 to 2.27.

This study offers several advantages over previous work. First and foremost is the size of the sample. It is large enough to permit a unique analysis of the effects of first snowfalls (by definition, limited to 1 per year per state). The sample permits us to measure snowfall on a daily basis, not merely monthly, as in some previous research.[7,9,11,12] Given the large number of years and states covered, in multivariate analysis we can control for state, year, and month fixed effects. This approach allows us to rule out a number of potential confounders. We can conclude that our findings reflect weather conditions and driver behavioral responses, rather than road conditions and other environmental factors. In the case of the first snow phenomenon, we can even say that the effects are probably due to behavioral responses as distinct from weather conditions, as we control for time since last precipitation and for intensity (amount) of precipitation.

The data are not perfect, however. They lack information on driving frequency and on-the-road driver behavior. Also, crashes may be more likely to be unreported in snowy conditions, causing us to underestimate the true relative crash rate in such conditions (although this is probably less of a concern for fatal crashes). Finally, the lack of data on nonfatal-injury and property-damage-only crashes for other than a sample of the states and for years during the 1990s, while still yielding large numbers of observations, restricts our ability to detect significant first snowfall effects for other than fatal crashes.

It is important to keep in mind that first snowfalls represent just a small fraction of exposure to inclement weather that drivers face each year. Thus, while these relative risks are high, the absolute risks in terms of total mortality and morbidity are modest. The estimates in Table 2 suggest that, for example, if drivers were as safe on first snow days as they are on other snow days during the year, approximately 12 fatal crashes and 210 nonfatal-injury crashes would be avoided in the United States each year. These results, combined with the comparable risks of second and third snow days reported earlier, imply that about 30 fatal crashes and 600 nonfatal-injury crashes in total might be avoided on the first 3 snow days of the year if drivers were more prepared.

While first snowfalls are once-a-year events, snowfalls in general account for a substantial period of exposure to inclement weather: 18 snow days per year for an average state and 66 snow days per year for a state such as New York. While our results suggest that snowfalls in general do not increase fatal crashes, they also suggest substantial increases in nonfatal crashes. On the basis of our results in Table 2, we estimate that snowfall in general in the United States each year leads to an additional 45 000 nonfatal-injury crashes and 150 000 property-damage-only crashes, relative to what we would expect if these days were dry.

Both the National Research Council[1] and the American Meteorological Society[2] have issued recent reports calling for a variety of technological and human systems measures to reduce the injury and property damage toll of weather-related crashes. The results presented here can help to evaluate the potential benefits of these measures. They do not, however, answer the question of whether adoption of such measures is warranted. Resolution of that question awaits a complete analysis of the costs and benefits of implementing these interventions. ■

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Contributors

D. Eisenberg conducted the empirical analysis. K.E. Warner had the original idea to explore "first snowfall" effects on the basis of his experiences with Michigan winters. Both authors shared in the conception of the study, design of the analysis, and writing of the results.

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Human Participant Protection

No human subjects were involved in this research.

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