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Effects of winter precipitation on automobile collisions, injuries, and fatalities in the United States

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ABSTRACT

To better understand the links between winter precipitation (snow, sleet, and freezing rain) and travel risk, data on weather conditions and vehicle crashes, injuries and fatalities are gathered for 13 U.S. cities. A matched pair analysis is used to construct event-control pairs to determine the relative risk of crash, injury, and fatality. Winter precipitation is associated with a 19% increase in traffic crashes and a 13% increase in injuries compared to dry conditions. The type of winter precipitation (snowfall vs. freezing rain, ice pellets, or sleet) had no significant impact on the relative risk of crash. The relative risk of crash was significantly higher during the evening (1800–2359 local time) than during other times of the day. More intense precipitation led to increased relative risk of crash and injury compared to less intense precipitation. Relative risk of crash, injury, or fatality was not significantly higher during the first three winter precipitation events of the year as compared to subsequent events. The relative risk of both winter precipitation crash and injury showed no significant trend during the 1998–2008 period. Sensitivity of U.S. cities to winter precipitation varies from city to city in a manner that is not easily explained. Future research will be required to determine which safety interventions are most effective in each city and revise or expand safety programs appropriately.

1. Introduction

In 2010, the World Health Organization declared 2011–2020 the “Decade of Action for Road Safety” in response to the enormous toll that roadway crashes take on individuals, communities, and national economies (World Health Organization [WHO], 2013). In 2010, 1.24 million people were killed on the world's roads (World Health Organization [WHO], 2013). Despite declines in the number of motor vehicle crashes, injuries, and fatalities in the United States since the 1960's (National Highway Traffic Safety Administration [NHTSA], 2014), nearly 34,000 fatalities, 2.4 million injuries, and 5.6 million vehicle crashes occurred in 2012 (National Highway Traffic Safety Administration [NHTSA], 2014). Motor vehicle crashes in the U.S. in 2010 had an economic cost of $277 billion, equal to 1.9% of the U.S. Gross Domestic Product in 2010 (Blincoe et al., 2014).

A number of factors may be involved in a motor vehicle crash. In 2010 in the U.S., alcohol was a factor in 34% of fatal crashes; excessive speed was a factor in 32% of fatal crashes, and distracted driving was responsible for 10% of fatal crashes (Blincoe et al., 2014). These crashes combined accounted for nearly 60% of the economic costs of collisions in the U.S. in 2010 (Blincoe et al., 2014). While use of alcohol, speeding, and distracted driving are within the control of the driver, there are a number of environmental factors that affect the likelihood of driver error and crash, including weather conditions. In the U.S., snowfall leads to an estimated additional 45,000 additional injury-causing crashes and 150,000 property damage crashes per year relative to what would be expected if those days were dry (Eisenberg and Warner, 2005). Winter precipitation was a factor in 27,326 fatal motor vehicle crashes that resulted in 31,159 deaths for the period 1975–2011, an average of over 850 deaths per year (Black and Mote, 2015).

Since the early 1970s, several studies have examined winter precipitation and its influence on motor vehicle crashes; Table 1 of Andrey et al. (2003) lists a number of studies conducted from the 1970s through the early 2000s. More recent work has examined trends in weather related crash risk, driver adaptation, and collision and injury risk in Canada (Andrey, 2010; Andrey et al., 2013; Mills et al., 2011), Europe (Brijs et al., 2008; Fridstrøm et al., 1995), and the effects of winter precipitation on collisions, injuries and fatalities in the U.S. (Black and Mote, 2015; Eisenberg and Warner, 2005). These studies consistently demonstrate that risk of both collision and injury are significantly elevated during winter precipitation. Meta-analysis of 34 studies on weather and traffic crashes by Qiu and Nixon (2008) found that snowfall can increase the crash rate by 84% and the rate of injury by 75%, while fatality rates only increased 9% after accounting for reductions in traffic volume. Eisenberg and Warner (2005) found that snowfall days had fewer fatal crashes with the exception of the first snowfall of

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Table 1
Study cities.

City	Period of record		Counties used for crash data	Airport used for weather data
	Start	End		
Little Rock, AR	1998	2010	Pulaski, AR	Little Rock Adams Field (KLIT)
Mt. Shasta, CA	2005	2010	Siskiyou, CA	Mount Shasta (KMHS)
South Lake Tahoe, CA	2005	2010	El Dorado, CA	Lake Tahoe Airport (KTVL)
Atlanta, GA	1996	2008	Fulton, Clayton, and DeKalb, GA	Hartsfield Jackson Intl. (KATL)
Cahokia/E. St. Louis, IL	1997	2010	St. Clair and Madison, IL	St. Louis Downtown (KCPS)
Chicago, IL	1996	2010	Cook and DuPage, IL	Chicago O'Hare Intl. (KORD)
Baltimore, MD	1996	2008	Anne Arundel, Baltimore City, and Howard, MD	Baltimore Washington Intl. (KBWI)
Duluth, MN[a]	1996	2010	Saint Louis, MN	Duluth Intl. (KDLH)
Minneapolis/St. Paul, MN[a]	1996	2010	Hennepin and Ramsey, MN	Minneapolis St. Paul Intl. (KMSP)
Buffalo, NY[b]	1996	2009	Erie, NY	Buffalo Niagara Intl. (KBUF)
New York, NY[b]	1996	2009	New York, Bronx, Kings, Queens, and Richmond, NY	LaGuardia Airport (KLGA)
Cincinnati, OH	1997	2010	Hamilton, OH	Cincinnati Municipal (KLUK)
Cleveland, OH	1996	2010	Cuyahoga, OH	Cleveland Hopkins Intl. (KCLE)

[a] Minnesota crash data unavailable for 2003.
[b] New York crash data unavailable for 2001.

the year, which had an elevated fatality rate, especially in the elderly. However, an 18% increase in fatality rate was found after adjustment for reduced traffic volume during snowfall days (Eisenberg and Warner, 2005).

Available research suggests that driver responses are insufficient to completely offset the risk of driving in weather conditions, which make vehicle handling more difficult, reduce traction, or reduce visibility, which leads to increases in crash rates (Andrey et al., 2013; Eisenberg and Warner, 2005). The magnitude of the increase in crash rates depends on factors such as weather conditions (e.g., precipitation type or intensity), time of day, and previous experience with winter precipitation. In a study of 23 Canadian cities, Andrey et al. (2013) found that drivers do not become acclimated to or experience reduced risk of crash during frequently experienced environmental conditions. Further, drivers are less likely to reduce speed in rural areas or areas with higher posted speed limits during both rainfall and snowfall, increasing crash risk as compared to urban areas or areas with lower speed limits (Andrey et al., 2013). Finally, Andrey (2010) found no discernable trend in relative risk (the probability of an event occurring in an exposed group compared to a non-exposed group) of crash due to snowfall in 10 Canadian cities during the period 1984–2002, indicating that casualty rates due to snowfall declined in ways consistent with the overall trend of decreasing vehicle collisions.

These studies leave several unanswered questions. First, what are the spatial patterns of the relative risk of vehicle collision, injury, or fatality during winter precipitation in the U.S.? The Canadian studies (Andrey et al., 2003, 2013; Andrey, 2010; Mills et al., 2011) reveal significant spatial variations in the relative risk of crash and injury across Canada, and previous work in the U.S. by Eisenberg and Warner (2005) examines relative risk in aggregate for the entire U.S. and therefore cannot address this question. Further, Eisenberg and Warner (2005) only examine non-fatal injury and property damage crashes for the 1990s, and this study provides an updated examination of these crashes. Secondly, do factors which were found to affect the relative risk of crash in Canada have a similar effect in the U.S., and do factors such as the type of winter precipitation have an effect? Finally, is the trend in relative risk of crash during winter precipitation in the U.S. similar to the trend (or lack thereof) in Canada?

This study addresses these questions by examining automobile crashes, injuries, and fatalities during winter precipitation events and control periods for 13 U.S. cities based on data from 1996–2010 and calculating the relative risk of crash due to winter precipitation. Study cities were chosen to allow analysis of crash risks across different climatic regions of the U.S. and to assess the effects of previous experience with winter precipitation based on the frequency of occurrence in each city. Risk rates were calculated for a number of factors identified in previous research, including precipitation type (snow vs. freezing rain and sleet), precipitation intensity, time of day, and the difference in risk between the first winter precipitation event of the year and subsequent events. Given the number of fatalities, injuries, and property damage that result from vehicle crashes, it is important to examine the characteristics of collisions that involve winter weather in order to determine the vulnerability of U.S. travelers to these events and to mitigate their effects.

2. Data and methods

2.1. Data sources

Analysis of collision risk due to winter precipitation requires two primary datasets: meteorological data and motor vehicle crash data. Hourly meteorological data from Automated Surface Observing System (ASOS) stations were used as they are available with high temporal resolution (i.e., hourly) and report the type of precipitation (if any) occurring at each observation. Due to their automated nature, ASOS stations are unable to report actual hourly snowfall values and instead report the liquid equivalent amount of precipitation that accumulated in the previous hour. Liquid equivalent measurements are obtained through melting of frozen precipitation that reaches the rain gauge. Converting liquid equivalent measurements back to snowfall amounts is difficult, as the snow ratio can vary from approximately 3:1 (3 in. of snow per inch of liquid) up to 100:1 in some situations (Roebber et al., 2003). ASOS stations may underreport winter precipitation due to changes in airflow near the gauge that can reduce the precipitation reaching the gauge or remove precipitation from the gauge before it is melted and measured (Rasmussen et al., 2012). Evaporation as the winter precipitation is melted for measurement and clogging of the recording mechanisms can exacerbate the ASOS underreporting problem (Rasmussen et al., 2012). Despite these issues, ASOS data was used in this analysis due to its relatively high temporal resolution and ability to differentiate between precipitation types. Given the difficulty of the liquid to snow conversion and the desire to compare precipitation totals from three types of winter precipitation (snow, sleet, and freezing rain), liquid equivalent precipitation as reported in the ASOS data was used as the source for precipitation intensity and accumulation for this study.

Motor vehicle crash data was obtained from the National Highway Traffic Safety Administration's (NHTSA) State Data System (SDS). Established in the early 1980s, the SDS consists of computer files coded directly from traffic crash reports that occur in each of 32 states that participate in the system and contains information on counts of property damage only (PDO) crashes, and the number of fatalities and injuries from motor vehicle crashes. However, the system is far from comprehensive, as some states only provide limited data or for a limited