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Effects of extraordinary snowfall on traffic safety

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ABSTRACT

Snowfall affects traffic safety by causing changes in roadway surface and visibility that result in crashes, spinouts, and breakdowns. Using data collected at a site that regularly receives nearly 1000 cm of snow during the snow season, this study examines the impact of snowfall quantity, gap between snow events, and weather conditions on crash and incident frequencies. Estimation results from regression analysis show that snowfall severity significantly impacts crashes and incidents but the impact diminishes marginally with each additional centimeter of snow. Gap has a significant fixed effect on crashes but its impact on incidents varies significantly across observations. The effect of the mixed precipitation condition is smaller in comparison to an all-snow condition. These results will help inform policy for snow removal and traffic enforcement in areas of high snowfall.

1. Introduction

Snowfall has long been understood to be a major contributor to elevated crash rates during the winter season. As snow accumulates on the roadway surface, it can reduce traction for both braking and steering. While prior research has mainly focused on urban areas with low to moderate amounts of snow, this study focuses on a section of rural freeway in California with very high annual snowfall. This level of snowfall enables researchers to make stronger conclusions concerning traffic safety in snow than in the typical urban location with a far smaller snowfall quantity. Frequent snow events at the site also make it possible to study the effect of the number of days between storms, referred to as "gaps." With anticipated temperature increases due to climate change, mixed precipitation conditions may become more common in areas that have traditionally seen more snow. Comparing all-snow to the mixed condition is therefore an important subject of interest. The frequent weather events in this area allow for comparison of the all-snow to the mixed precipitation condition and can forecast how climate change may affect traffic safety. Lastly, by examining all police responses rather than just crashes, we can examine the effect of snow on the likelihood of other incidents such as vehicle breakdowns and spinouts.

This analysis is relevant to sites with similar snow amounts and traffic volumes as well as sites with lesser amounts of snow. Similar sites include several areas in the western United States, such as the passes of Washington, Colorado, and Utah. Sites with similar characteristics also exist in Europe near the entrances of the major trans-Alpine tunnels as well as in Japan on the freeways of Hokkaido and northern Honshu. Examining an area of frequent and heavy snow such as the study area will also inform policy for locations that experience lesser snowfall, including the northeast United States, Quebec, southern Japan, and Eastern Europe.

The main objective of this study is to examine three weather-related variables and their relationship to the number of crashes and other hazards (referred to as "incidents"). The first variable is the severity of snowfall. The second is the time between two successive snow events (gap). The third is the presence of a mixed precipitation condition in which a portion of the study area experiences snow while other portions experience rain. These mixed precipitation storms were compared to all-snow and all-rain events with dry and clear days as the baseline. We used statistical analysis to explore the impact of these variables on crashes and incidents. In addition, we documented the temporal variation of police responses to crashes and incidents by months of the year and calculated crash rates and incident rates within the study area.

The remainder of the paper is organized as follows. Section 2 summarizes previous research and Section 3 describes the study site in detail. Section 4 describes our data resources and how we processed the raw data for use in this work. Section 5 presents regression models employed in our analysis of the raw data. Section 6 presents basic empirical results on police responses and estimation results from regression analysis. Section 7 discusses the regression analysis results focusing on impact of weather variables on response. Finally, Section 8 reports our conclusions.

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2. Background

2.1. Generic effects of snowfall

Most prior research has examined the effect of winter weather on traffic safety with snowfall severity as a discrete variable of up to three categories. In an examination of the relationship of winter weather to crash rates on local roads and freeways in the United States, Eisenberg and Warner (2005) reported that the first snowy day of the year is 14% more dangerous than an average snowy day. Furthermore, they found that although snowy days are 7% less likely to produce a fatal crash, non-fatal injury crashes increase 23% on snowy days and property damage only (PDO) crashes increase 45%. In earlier work, Eisenberg (2004) attributed the lag effect of reduced crash rates after precipitation events to the clearance of oil from the roadway surface and to increased driver awareness.

2.2. Site-specific studies in the United States

A series of studies have examined the effect of snowfall on freeways at specific locations within the United States. Shankar et al. (1995) examined factors leading to crashes in Snoqualmie Pass in Washington, a location very similar to our study area in California. Shankar examined how crash rates were affected by snowfall and extreme geometrics. His primary conclusion was that reductions in sharp curves and steep grades could dramatically affect the quantity of crashes during adverse weather, particularly snow. For example, the snowfall-grade indicator variable, which captured snow totals over 5 cm and grades over 2%, showed a 33% increase in crashes as compared to a dry winter day. In Iowa, Khattak and Knapp (2001) found that freeway crash rates per million kilometers driven during snow increased more than 1000% for injury crashes (0.2–2.9) and more than 2000% (0.2–5.1) for PDO crashes. Similarly, Maze et al. (2006) found that 21% of the crashes on one section of Iowa freeway occurred during snowy days, although these days comprised only 5% of the year. Additionally, Khattak and Knapp found that wind speed during snowfall increased crash rates and that more crashes occurred during the weekend. This finding was consistent with that of Knapp et al. (2000), who found that overall crash rates on Iowa freeways were 0.41 on clear dry winter days and 5.86 during snowstorms; both snowstorm intensity and duration significantly predicted crash rates. Lastly, in a meta-analysis, Qiu and Nixon (2008) found that the average crash rate increased by 84% in all types of snow, although they noted the large confidence interval for these findings.

2.3. Site-specific studies outside of the United States

Outside of the United States, location-based examinations of the effect of snowfall on crashes have been conducted in both Canada and Europe. In Canada, Brown and Baass (1997) and Andrey et al. (2003) looked at crashes in the larger Canadian cities. Brown and Baass concentrated on seasonality in Quebec and found that the winter months had the lowest incidence of fatal and serious injury crashes but had the highest rates of PDO crashes. Andrey et al. surveyed six major Canadian cities and found that the relative risk of crashes ranged from 1.2 in the snowiest city (Quebec City) to over 2.0 in a dry Midwestern site (Regina). El-Basyouny and Kwon (2012) focused on one specific snowy Canadian city (Edmonton) and reported that severe collisions increased by 3.3% per cm of snowfall and PDO crashes increased by 5.8% per cm. Andrey (2010) followed up his 2003 study with a comparison of crash rates during inclement weather from 1984 to 2002. While he found dramatic decreases in fatalities during rain, possibly due to new braking and traction technologies, there was no significant difference in fatality rates during snowfall over the study period. In Sweden, Norrman et al. (2000) looked at the relationship between crashes and proper application of winter maintenance. In the UK, Andersson and Chapman (2011a) found that increased temperatures were associated with fewer days of icy roadways and subsequently had fewer crashes, but cautioned against reducing winter maintenance capabilities. Andersson and Chapman (2011b) conducted a study similar to their previous work and concluded that increased temperatures would be unlikely to lead to fewer winter crashes.

2.4. Methodology background

Since the mid-1990s there has been a slow and steady increase in the intricacy of analysis tools in the examination of crash frequency. As described in Lord and Mannering (2010), Poisson regression was initially used as it was considered to be a reasonable tool for studying non-negative integer data. For example, Joshua and Garber (1990) used Poisson regression to examine variables contributing to truck crashes in three different environments. However, overdispersion of data becomes a problem if the variance of crash data exceeds the mean, which violates a requirement of Poisson. Recognition of this issue led researchers to move towards more complex tools such as negative binomial regression, as used by Shankar et al. (1995) and Abdel-Aty and Radwan (2000). While negative binomial regression has been widely used and continues to be used to analyze crash frequency, there are also limitations to this modeling strategy, as described in Lord (2006). Random-effect and random-parameter models have then been developed for count data analysis to capture heterogeneity in observations. Some examples include Aguero-Valverde and Jovanis (2008), which employed random effects to examine spatial correlation; Milton et al., (2008), which used the mixed logit model to analyze highway accident severities; and Anastasopoulos and Mannering (2009), which used random-parameter negative binomial models. Further reading on new frontiers in crash frequency analysis can be found in Mannering and Bhat (2014) and Washington et al. (2011). Model selection for this paper is described in Section 5.

2.5. Miscellaneous

In California within our study area, there are strict regulations requiring the use of snow chains, studded tires, or four wheel drive (4WD) during snow events. Recent research by Garder (2014) found that 4WD vehicles are not under-represented in winter crashes and are therefore not “safer” than non-4WD vehicles, although there are certain subsets of 4WD vehicles that appear to be underrepresented in the data and safer than others.

3. Study site

The study area for this analysis is a 55-km section of Interstate 80 (I-80) in California between kilometer-post 250 and 305, passing through the Sierra Nevada Mountains. The Sierra Nevada Mountains are significant barriers to interstate commerce; there are no freeways across the mountains within 500 km either to the north or south of the study area. The entire study area is above 1600 m of elevation and the vertical profile is shown in Fig. 1. The section includes the portion of freeway that passes through Donner Pass, a 2200 m high point in the Sierra Nevada Mountains that is well known historically for prodigious amounts of snow. Donner Pass is named for a pioneer party that was stranded in a snowstorm while trying to cross the pass in October of 1846, and currently hosts the California highest points for both the first transcontinental railroad and the I-80 freeway. On the west side of the pass is