# Protection from Nature's Fury: An Analysis of Fatalities and Injuries from F5 Tornadoes

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## Abstract

Improved technology and warnings seem to have reduced tornado casualties over time. We subject this conventional wisdom to empirical scrutiny by examining the determinants over time of casualties from the strongest (F5) tornadoes in the U. S. since 1900. We limit analysis to F5 tornadoes to control for the strength of storms and then control for economic and demographic characteristics of the storm paths in a regression analysis of casualties. We find significant, negative time trends over the periods 1900 to 1999 when controlling for population density and 1950 to 1999 when also controlling for income. Our results indicate that everything else equal, fatalities from an F5 tornado were 40% lower in 1999 than 1950 and 90% lower in 1999 than 1900.

## Introduction

Tornadoes pose a risk to life and property throughout the United States. Over the decades the National Weather Service has worked to issue reliable tornado warnings and educate the public about tornado safety.[1] The national time series of tornado fatalities suggests the value of these efforts. Brooks and Doswell (2002) document declines in the average annual tornado death toll from 260 to 54 between 1912 and 2000 and the annual fatality rate per million residents from 1.8 in 1925 to .11 in 2000.

The annual tornado death toll, however, depends on a number of factors besides the effectiveness of tornado warnings and awareness programs, such as the number, strength and location of the tornadoes occurring each year. Fatalities could be low in a year either because few strong tornadoes occur or the strong tornadoes happen to strike unpopulated areas. While some of these factors will balance out over several years, tornadoes affect only a tiny portion of the land area of the United States each year; Schaefer et al. (2002) estimate that the maximum annual probability of tornado occurrence in the United States is .0006. Given that a few violent (F4 or F5) tornadoes cause a disproportionate percentage of fatalities, annual fatalities may not balance out even over several decades. Consider tornado rates and fatality rates in Massachusetts, Connecticut and Rhode Island. Over the period 1950 to 1995, the average annual number of tornadoes per 10,000 square miles land area was 3.4 in Massachusetts and 2.4 in Connecticut and Rhode Island, suggesting these states face similar tornado climatologies. The average annual death rate per million residents from 1950 to 1999 was .364 in Massachusetts compared to .021 in Connecticut and Rhode Island, a difference attributable almost entirely to one tornado, the June 1953 Worcester F4 tornado which killed 90 persons.[2] Changnon and

Hewings (2001) report a downward time trend in tornado catastrophe loses, which suggests perhaps that the worst tornadoes have struck relatively unpopulated areas in recent decades.[3]

We investigate whether a statistically significant downward trend in tornado casualties exists when controlling for the strength and locations of tornadoes. One approach would be to control for the number, location and strength of all tornadoes each year in regression analysis of annual tornado deaths. But with about 1000 tornadoes per year in the U.S., the data requirements of this approach are overwhelming. Instead we use the individual tornado as the unit of observation and consider only storms rated F5 on the Fujita Scale. Including only F5 tornadoes in the United States since 1900 keeps data requirements manageable (77 storms total) and controls for the strength of storm. We estimate two casualty models, one with population density for the counties in the storm paths in addition to the time and month of the storm for the entire data set, and a second for tornadoes since 1950 with county income included as a control variable. If tornadoes are becoming less dangerous over time, an F5 tornado striking a similar path in 2000 should produce fewer casualties than in 1900 or 1950. A time trend variable in our regression provides a test of the effect of improved tornado warnings and awareness.

We indeed find a statistically significant downward trend for both fatalities and injuries over both time periods, which supports the conclusion that tornadoes have become less lethal. The point estimate of the time trend over 1900 to 1999 indicates that fatalities were 91% lower and injuries 37% lower for F5 tornadoes at the end of the 20$^{th}$ Century than at the beginning, while fatalities were 41% lower and injuries 12% than in 1950 when also controlling for income. Population density and income are also significant determinants of fatalities and injuries, with casualties higher in more densely populated and poorer storm tracks.

**Empirical Method and Variable Definitions**

Our data set includes all tornadoes rated F5 in the United States in the 20th Century. The sources for tornado records were the Storm Prediction Center's national tornado archive for storms since 1950 (SPC 2000) and Grazulis (1993) for storms prior to 1950.[4] Seventy seven F5 tornadoes have occurred in the U.S. since 1900, with the first in May 1905 in Oklahoma and the most recent in May 1999 also in Oklahoma. The SPC archive includes separate records for tornadoes which strike two or more states. Between 1950 and 1999 the 51 F5 tornadoes produced 64 state tornado segments, and a total of 90 storm segments for the period 1900 to 1999. The state storm segments comprise our data points for analysis.

We expect that tornadoes should have become less deadly over time as the quality of tornado warnings, communications technology for disseminating these warnings, and public awareness of tornadoes and precautions to take in the event of a tornado have all improved. But improved warnings and public awareness are only one factor which determine tornado fatalities. To conclude that tornadoes have become less deadly over time, we must control for other factors which affect casualties, such as the characteristics of the storm path and time of day of the tornado. Consequently we estimate the following regression model of fatalities from an F5 tornado:

$$\text{Fatalities} = f(\text{Density, Income, Season, Evening, Night, Year}).$$

We estimate the same model of injuries. The Census Bureau reports county level income only back to 1950, so we estimate the model for 1900 to 1999 without income.

By restricting analysis to F5 tornadoes, we control for the intensity of the storm. Our control variables account for storm path characteristics and additional storm characteristics. The

Year variable will then capture any changes in tornado lethality over time, all other things held constant.

The definition and expected effect of the independent variables on casualties are as follows. Density is the number of residents per square mile averaged for each of the counties struck by the tornado. We use county population from the decennial census and a linear interpolation to estimate county population in a year. We expect a positive sign for Density in the casualty functions as tornadoes striking more populated areas should produce more casualties. Income is median family income in thousands of 1999 dollars averaged for each of the counties struck by the tornado. Annual income estimates were again generated by linear interpolation from decennial censuses and converted to 1999 dollars using the national Consumer Price Index. Average housing quality should be higher in counties with higher median incomes and this should provide residents greater protection. Also wealthier communities might also be more likely to have tornado sirens to alert residents. Consequently we expect a negative sign for income in the casualty functions. Year is a linear time trend variable constructed by subtracting 1900 or 1950 as appropriate from the year in which the tornado occurs; thus this variable ranges from 5 to 99 in the full century regression and 2 to 49 in the post 1950 regression. A negative and significant coefficient for time in the casualty models indicates that F5 tornadoes have become less dangerous over time and represents our main test. Season is a dummy variable based on the month of the year in which the tornado occurs. Season equals one for tornadoes in the months of March, April, May or June and zero for tornadoes in any other month. Residents might be more alert to and prepared for tornadoes during spring months when most tornadoes occur and thus a tornado outside the normal season might catch residents unprepared and produce more casualties. Tornadoes at different times of day pose different types of threats.

Most residents will be at work or school during the day, while at night most residents will be asleep and perhaps unable to take shelter. We divided the storms into three time categories with dummy variables for the categories. Day equals one for tornadoes which struck after 6AM and before 6PM and zero otherwise, Evening equals one if the tornado struck between 6PM and 10PM local time and zero otherwise, while Night equals one for tornadoes which struck after 10PM. All three of these time of day variables cannot be included in the regression model, and thus we omit Day. The coefficients on Evening and Night indicate the effect of storms at these times compared to a storm occurring in the afternoon. We have no strong expectation concerning the signs of Season, Evening and Night, which we include as controls.

**Data Description and Preliminary Analysis**

The 77 F5 tornadoes in our sample struck 21 states and 184 counties. Fatalities in the 90 state segment records in our data set range from zero to 695, with a mean of 29.7 and median of 9.0. Not all F5 tornadoes are lethal, as 14 of our storm segments produced no fatalities, while five storms killed over 100 people. Injuries ranged from zero (9 times) to 2027 with a mean of 193.2 and median of 71.0. Forty storms injured 100 or more people and ten injured 500 or more. Eighty three storms occurred in Season (March-June), while the time of day break down was Day 51, Evening 31 and Night 8.

Table 1 presents total fatalities and injuries and casualties per tornado broken down by decade.[5] Both fatalities per tornado and injuries per tornado were greatest in the 1920s at 140.8 and 488.7 respectively, due to the Tri-State tornado of 1925, the deadliest tornado in U.S. history. Fatalities per tornado appear to trend down; the last four decades of the 20$^{th}$ Century had the four lowest decadal average fatalities per tornado. A trend in injuries is less apparent.

Injuries per tornado were lowest in the 1900s and 1910 respectively, but then after the 1920s ranged from 134.8 to 250.9. The correlations between the time trend variable and casualties are -.219 for fatalities and -.0306 for injuries.

The population density of the storm track counties ranged from .778 to 2219 persons per square mile, with a mean of 114.4. Income (in 1999$) of the 1950-1999 storm tracks ranged from $5906 to $63095 with a mean of $33490. Both population density and income seem to affect tornado fatalities since 1950. The ten tornadoes with the lowest population density storm tracks killed a total of 77 persons and injured 689, while the ten storms with the highest population density storm tracks produced 344 fatalities and 4357 injuries. The ten tornadoes in the poorest storm tracks killed 281 and injured 2072 persons while the ten tornadoes with the wealthiest storm tracks produced 154 fatalities and 2477 injuries. The differences in casualties per storm are statistically significant at the .01 level in a one-tailed test for population density, although neither difference is statistically significant at even the .10 level for income. The correlation between Density and fatalities is +.082 while the correlation between income and fatalities is -.145. Income has increased over time, and the correlation between Income and Year is +.760, so failure to include Income as a control would lead to an erroneous conclusion regarding the time trend. The relationship between population density and fatalities is much less apparent over 1900-1999. The ten tornadoes in the lowest population density storm tracks killed 359 and injured 1607 persons, while the ten tornadoes in the highest population density storm tracks killed 344 and injured 4357 persons. The correlation between Density and fatalities over the entire sample is -.0244.

**Regression Estimates and Fatalities Predictions**

The trend in casualties visible in Table 1 may be apparent and not real, since storm path characteristics and time of day are not controlled for in decade averages. We now estimate regression models of fatalities to determine if casualties from F5 tornadoes have declined over time when controlling for storm path and time of the tornado. We begin with the 1950-1999 period when we can also control for income, then turn to the entire sample. The casualties from a tornado take on integer values with a large proportion of zero observations, what economists refer to as count data. The count nature of the data make estimation of casualty functions using ordinary least squares inappropriate. Instead we employ a Poisson regression model, which is typically used by economists for count data (Greene 2000, pp.880-886). The Poisson model assumes that the number of fatalities (or injuries) is a random variable with a Poisson distribution. The parameter $\lambda$ of the Poisson distribution is assumed to be a function of the independent variables. The regression analysis attempts to identify this relationship. The model is estimated using maximum likelihood estimation assuming that the log of the conditional mean of casualties is linear function of the explanatory variables.

Table 2 presents the regression results for 1950 through 1999. The first column reports the determinants of fatalities and the second column the determinants of injuries. The columns report both the point estimate of the coefficient plus the standard error of the estimate. A Chi-square test determines whether the coefficient is statistically different from zero. Density is a positive and highly significant determinant (at better than the .0001 level) of both fatalities and injuries. Not surprisingly, more casualties occur in more highly populated counties. Year reduces both fatalities and injuries, and is significant at the .01 level for fatalities and the .05 level for injuries. This result confirms statistically that tornadoes have become less dangerous over time. Given the other factors, especially including income, that we control for, we attribute

this time trend to improved tornado warnings and public awareness. Income is also a negative and significant determinant (at the .01 level) of both fatalities and injuries, so wealthier communities protect themselves better against tornadoes. Of the time of day and year variables, only Evening is a significant (positive) determinant of fatalities, while Season, Evening and Night are all significant determinants of injuries. Tornadoes in the Evening are more deadly than during the day, while tornadoes out of season and during the Evening or Night produce more injuries than comparable storms in season or during the Day.

The dependent variable in the Poisson model is the natural logarithm of expected casualties, rendering the interpretation of the magnitude of the coefficients in Table 2 challenging. To illustrate the magnitude of the impact of the independent variables on casualties, Tables 3, 4 and 5 report predicted casualties from the models for an F5 tornadoes in various circumstances. Table 3 indicates the effect of Year. We calculate casualties from the model in 1950 and 1999. We calculate casualties for the 1950 national values of Density and Income with year set to 1950 and 1999, as well as for 1999 national values of Density and Income with year set to 1950 and 1999.[6] Examination reveals that expected fatalities and expected per tornado have fallen by 41% and 13% between 1950 and 1999. The smaller reduction in injuries may be due to better reporting of injuries in recent years. For instance, in Oklahoma following the May 3rd F5 tornado, the Oklahoma Health Commissioner made tornado casualties reportable conditions, requiring hospitals in the state to report patients treated (Brown et al. 2002). More complete reporting would partially offset a reduction in actual injuries.

We also calculate the 95% confidence interval for the time trend effect using 1950 values for population density and median family income. The point estimate in 1999, from Table 3, is 13.4 fatalities. Predicted fatalities using the lower and upper bounds of the 95% confidence level

for the estimate of the time trend coefficient are 9.23 and 19.5 fatalities, which yield a range for the predicted percentage reduction in fatalities of 15% to 60%.

Table 4 illustrates the effect of population density on casualties using 1999 national median family income and year value. Density is set equal to the minimum (5.25), mean (149.3) and maximum (2219) values for tornado tracks in the 1950-1999 data set. Density has a substantial effect on both fatalities and injuries. Expected fatalities are about 21% lower and expected injuries 18% lower at the minimum compared to the mean, while expected fatalities are thirty three times larger and expected injuries eighteen times larger at the maximum than the mean.

Table 5 illustrates the effect of income on casualties using 1999 national population density and time trend. Income is set equal to the minimum ($5,906), mean ($33,490) and maximum ($63,095) values for the tornado tracks. Income has a quantitatively smaller impact on casualties than population density, and has a larger impact on fatalities than injuries. Expected fatalities fall by more than half when moving from the lowest to highest storm track income value, while predicted injuries fall by about 25%. The impact of income on indicates that examining only the time series of fatalities will overstate the time trend, given the increase in real income over the last fifty years.[7]

Table 6 presents the Poisson regression estimates for fatalities and injuries using all F5 tornadoes from the 20$^{th}$ Century. Density is again positive and significant (at the .05 level) determinant of both fatalities and injuries; more casualties occur in more populated tornado tracks. The time trend is negative and highly significant (at better than the .0001 level) determinant of both fatalities and injuries. This again is the statistical evidence that tornadoes have become less lethal over time. Indeed the point estimates of the time trend coefficients are

larger in magnitude than in the 1950-1999 data set. Note however that since income is not included as a control, we cannot attribute all of this effect to improved warnings and awareness. The season and time of day dummy variables are generally all statistically significant in the full data set with large point estimates; only Season for injuries is insignificant. The time of day variables indicate that F5 tornadoes in the Evening or at Night are less dangerous than during the day, the opposite of the significant coefficients on these variables in Table 2.

Tables 7 and 8 illustrate the magnitude of the effect of time and population density on expected casualties. Table 7 illustrates the effect of the time trend on casualties, calculating expected casualties in 1900, 1950 and 1999 with the 1900 and 1999 national population densities for out-of-season tornadoes during the day. Fatalities were 91% lower and injuries were 37% lower in 1999 than 1900. Since income is not included in this model, we cannot attribute all of this decline to improved tornado warnings and increased tornado awareness. The estimates of predicted fatalities with the 1999 time trend and 1900 population density from the 95% confidence interval for the time trend coefficient are 7.32 and 10.1, for a range of 89.9% to 92.7% reduction in fatalities. Table 8 illustrates the effect of population density on predicted casualties, calculated with the 1999 time trend value and the minimum, mean and maximum storm track population densities in the full sample. The quantitative effect of population density is smaller than for the 1950-1999 period and larger for injuries than fatalities; expected fatalities are 56% higher at the maximum density than the minimum and expected injuries 142% higher at the maximum than the minimum.[8]

## Conclusion

We have estimated casualty functions for F5 tornadoes in the United States since 1900. Multiple regression controls for various factors influencing tornado casualties, including the time of day, year and the population density of the storm path, and allows for a more definite answer to the question of whether tornadoes have become less deadly over time. A downward trend in fatalities per tornado is apparent in decade totals but the reduction may be due to other factors (e.g., recent tornadoes perhaps not striking highly populated areas). We find a statistically significant, negative time trend on fatalities and injuries, confirming that at least the most powerful tornadoes have become less lethal over time. Indeed, our model suggests that expected fatalities per tornado were about 91% lower in 1999 than 1900. With income included as a control variable for F5 tornadoes since 1950, we find that tornado fatalities are 41% lower in 1999 than 1950. Our analysis also shows that injuries from an F5 tornado were about 37% lower in 1999 than 1900 and about 13% lower in 1999 than in 1950. Higher income reduces fatalities, which is as expected, since housing quality is higher in wealthier communities and they also may be more likely to have tornado sirens. Real income has risen over time, so our inability to control for income in the 1900-1999 analysis implies that the time trend effect here is not all improved warnings and awareness. Our year variable measures the combined effects of all factors changing over time not controlled for by the other independent variables. With income controlled for in the 1950-1999 model, we believe the most plausible remaining factor is indeed tornado warnings and awareness. Actually our two models yield reasonably consistent estimates of the combined effects of income and time on fatalities. The 1900-1999 model estimates that fatalities were 70% lower in 1999 than in 1950, while with the 1950-1999 model the combined effect of income and time is a 63% reduction in fatalities between 1950 and 1999.[9]

Based on an analysis of the time series of national annual tornado deaths since 1876, Brooks and Doswell (2002, p.360) estimate that without the reduction in the tornado death rate over the last seventy five years, the death toll in the 3 May 1999 Oklahoma City F5 tornado might have been 500, compared to the actual total of 36. Our estimate of a 41% reduction in fatalities between 1950 and 1999 when including income as a control suggests that the Oklahoma City tornado would have killed about 60 persons in 1950. The 95% confidence interval for the estimate of the time trend effect produces a range of 42 to 90 fatalities from this storm in 1950. Our estimate of a 91% reduction in fatalities over the 20$^{th}$ Century suggests that the death toll had this tornado occurred on a similar path in 1900 would have been about 400, although some of this reduction would be due to income and not warnings. Our results show that the National Weather Service's efforts to reduce tornado casualties through improved warnings and public awareness yielded significant safety benefits just on this one day.

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**Table 1**

F5 Tornadoes and Casualties by Decade

| Decade | # of Tornadoes | Total Fatalities | Fatalities per Tornado | Total Injuries | Injuries per Tornado |
|---|---|---|---|---|---|
| 1900s | 4 | 117 | 29.3 | 180 | 45.0 |
| 1910s | 5 | 89 | 17.8 | 330 | 66.0 |
| 1920s | 6 | 845 | 140.8 | 2932 | 488.7 |
| 1930s | 5 | 248 | 49.6 | 791 | 158.2 |
| 1940s | 6 | 288 | 48.0 | 1476 | 246.0 |
| 1950s | 18 | 481 | 26.7 | 3090 | 171.7 |
| 1960s | 13 | 214 | 16.5 | 3262 | 250.9 |
| 1970s | 19 | 245 | 12.9 | 3669 | 193.1 |
| 1980s | 4 | 27 | 4.5 | 539 | 134.8 |
| 1990s | 10 | 147 | 14.7 | 1572 | 157.2 |

**Table 2**

Poisson Regression Models of Tornado Fatalities and Injuries

| Independent Variable | Fatalities | Injuries |
|---|---|---|
| Population Density | **.0017*** (.0001)** | **.0014*** (.0000)** |
| Median Income | **-.0155*** (.0046)** | **-.0048*** (.0014)** |
| Year | **-.0109*** (.0039)** | **-.0029** (.0012)** |
| Season | -.158 (.0995) | **-.263*** (.0300)** |
| Evening | **.161** (.0692)** | **.155*** (.0217)** |
| Night | -.0487 (.339) | **.515*** (.0729)** |
| Intercept | **3.36*** (.134)** | **5.29*** (.0438)** |

Number of observations = 64. Standard errors in parentheses. Significant coefficients in bold; *, ** and *** indicate significance at the .10, .05 and .01 levels respectively. Models estimated with Poisson regression; the dependent is the natural logarithm of casualties.

**Table 3**

Effect of Time Trend on Casualties

| | Fatalities | Injuries |
|---|---|---|
| Density and Income at 1950 Levels (42.8 persons/mi$^2$ and $19,340) | | |
| 1950 (Year = 0) | 23.0 | 192 |
| 1999 (Year = 49) | 13.4 | 167 |
| Density and Income at 1999 Levels (79.6 persons/mi$^2$ and $48,950) | | |
| 1950 (Year = 0) | 15.4 | 175 |
| 1999 (Year = 49) | 9.05 | 152 |

Calculated from the 1950-1999 models reported in Table 2 assuming a tornado during the day (Day = 1) and out of season (Season = 0).

**Table 4**

Effect of Population Density on Casualties

| Population Density at | Fatalities | Injuries |
|---|---|---|
| Minimum (5.25) | 7.97 | 137 |
| Mean (149.8) | 10.2 | 168 |
| Maximum (2219) | 345 | 3040 |

Calculated from the 1950-1999 models reported in Table 2 assuming a tornado during the day (Day = 1) and out of season (Season = 0) in 1999 (Year = 49).

**Table 5**

Effect of Income on Casualties

| Median Income at | Fatalities | Injuries |
|---|---|---|
| Minimum ($5,906) | 17.6 | 187 |
| Mean ($33,490) | 11.5 | 164 |
| Maximum ($63,095) | 7.27 | 142 |

Calculated from the 1950-1999 models reported in Table 2 assuming a tornado during the day (Day = 1) and out of season (Season = 0) in 1999 (Year = 49).

**Table 6**

Poisson Regression Models of Tornado Casualties, 1900-1999

| Independent Variable | Fatalities | Injuries |
|---|---|---|
| Population Density | **.0002**** | **.0004**** |
| | **(.0001)** | **(.0000)** |
| Year | **-.0248***** | **-.0046***** |
| | **(.0008)** | **(.0003)** |
| Season | **.164*** | -.0476 |
| | **(.0950)** | (.0291) |
| Evening | **-.771***** | **-.313***** |
| | **(.0646)** | **(.0244)** |
| Night | **-1.85***** | **-1.85***** |
| | **(.379)** | **(.174)** |
| Intercept | **4.60***** | **5.56***** |
| | **(.105)** | **(.0364)** |

Number of observations = 90. Standard errors in parentheses. Significant coefficients in bold; *, ** and *** indicate significance at the .10, .05 and .01 levels respectively. Models estimated with Poisson regression; the dependent is the natural logarithm of casualties.

**Table 7**

Effect of Time on Casualties from 1900-1999 Models

| | Fatalities | Injuries |
|---|---|---|
| Density at 1900 Level (21.5 persons/mi$^2$) | | |
| 1900 (Year = 0) | 99.9 | 262 |
| 1950 (Year = 50) | 28.9 | 208 |
| 1999 (Year = 99) | 8.58 | 166 |
| Density at 1999 Level (79.6 persons/mi$^2$) | | |
| 1900 (Year = 0) | 101 | 268 |
| 1950 (Year = 50) | 29.3 | 213 |
| 1999 (Year = 99) | 8.68 | 170 |

Calculated from the 1900-1999 models reported in Table 6 assuming a tornado during the day (Day = 1) and out of season (Season = 0).

**Table 8**

Effect of Population Density on Casualties, 1900-1999 Model

| Population Density at | Fatalities | Injuries |
|---|---|---|
| Minimum (.778) | 8.55 | 165 |
| Mean (114.4) | 8.80 | 175 |
| Maximum (2209) | 13.3 | 400 |

Calculated from the 1900-1999 models reported in Table 6 assuming a tornado during the day (Day = 1) and out of season (Season = 0) in 1999 (Year = 99).

1. For details on tornado forecasting efforts see Doswell et al. (1999) or Golden and Adams (2000).

2. Tornado frequencies were taken from the map at the NOAA website at www.ncdc.noaa.gov/ol/climate.severeweather/small/avgtpsn.gif. The fatality rates are based on authors' calculations from SPC (2000) and decennial censuses 1950-2000.

3. Note though that Brooks and Doswell (2001) find that when adjusting damage for inflation and national wealth, the most damaging tornadoes in U.S. are evenly distributed over the past century.

4. To double check our search, we compared our list of records identified to a list of F5 tornadoes in the United States posted on the SPC website, and the lists were identical. The list was obtained February 3, 2003 from www.spc.noaa.gov/faq/tornado/f5torns.html. We thank Harold Brooks for providing us with the list of F5 tornadoes from Grazulis (1993).

5. The number of tornadoes during the first half of the century (26) is lower than during the last half (51), a difference which is statistically significant at the 10% level. The tornado record prior to 1950 may well be incomplete, which renders the 1900-1999 results somewhat suspect. Our primary interest though is in the 1950-1999 period when income can be included as a control.

6. The time of day and season effects are netted out by making the calculations relative to the excluded categories (Day, Out of Season). National population density was 42.8 and 79.6

persons per square mile and national median income in 1999$ was $19,340 and $48,950 in 1950 and 1999.

7. The Poisson model assumes the equivalence of the conditional mean and variance of the dependent variable. Our data exhibits evidence of over dispersion, a violation of this assumption. The negative binomial regression model is recommended as a generalization of the Poisson model in this case (Greene 2000, pp.886-8), although economists still sometimes employ Poisson regression even when the data indicates over dispersion. Negative binomial casualty models yielded estimates substantially similar to Table 2. For instance, the time trend in the negative binomial model yielded an estimated 40% reduction in fatalities and 28% reduction in injuries between 1950 and 1999.

8. Again we estimated these casualty models using negative binomial regression. In this case only the time trend variable was statistically significant, but its point estimate was nearly the same as from the Poisson model. The negative binomial models predict that fatalities were 95% lower and injuries 57% lower in 1999 than 1900.

9. The 70% lower figure is derived from comparison of the 1950 and 1999 fatality figures in Table 7. The 1950-1999 model in Table 2 with 1950 Density and 1999 income and year value predicts 8.50 fatalities, while predicted fatalities with 1950 Density, Income and year value from Table 3 are 23.0, yielding the 63% combined reduction.