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ORIGINAL PAPER

Tornado fatalities and mobile homes in the United States

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Abstract Fatalities from tornadoes have declined dramatically over the last century in the United States. Despite the overall reduction in tornado lethality, fatalities from mobile homes remain high. In fact, research suggests that the likelihood of a fatality in a mobile home is ten times or more than that in a permanent home. This study examines possible explanations of the mobile home tornado problem, including the potential for concentration of these homes in tornado prone states, the relation to Fujita Scale rating, and incidence during the day. We find that mobile home fatalities are concentrated in the Southeastern US, significantly more likely in weaker tornadoes, and occur disproportionately at night.

Keywords Tornadoes · Mobile homes · Fatalities · Injuries

1 Introduction

The tornado fatality rate in the United States has fallen considerably over the past century. Brooks and Doswell (2002), for example, estimate that the national fatality rate fell from 1.8 per million in 1925 to 0.11 per million in 2000, while Simmons and Sutter (2005) find that expected fatalities from F5 tornadoes fell by 91% between 1900 and 1999. Factors reducing lethality include tornado warnings of improving quality issued by the National Weather Service (NWS), new technologies to disseminate the warnings, and improved public response to warnings (Doswell et al. 1999). But standing out against this trend of reduced lethality has been the problem of tornado fatalities in manufactured or mobile

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homes.[1] The location of tornado fatalities confirms the public perception of the vulnerability of mobile homes: between 1985 and 2007, 43.2% (536 of 1240) of US tornado fatalities occurred in mobile homes. Mobile homes comprised 7.6% of US housing units in 2000, with an average household size below the national average. Consequently, the probability of a tornado fatality in mobile homes is estimated to be 10–15 times higher than in permanent homes (Brooks and Doswell 2002; Simmons and Sutter 2006).

The problem of tornado fatalities in mobile homes has alarmed many observers, and some have proposed stricter construction standards as well as mandates for tornado shelters in mobile home parks (American Meteorological Society 1997; Golden and Snow 1991; Golden and Adams 2000). On the other hand, other factors might explain some and perhaps much of the "mobile home problem." The Manufactured Housing Institute (2006) claims that the problem arises because manufactured homes are more likely to be located in suburban or rural areas more prone to tornadoes. If so, the mobile home problem may be a by-product of other vulnerabilities. The exact origins of that vulnerability are important because manufactured housing represents an affordable housing option for households of modest means (Beamish et al. 2001). Imposing tornado safety mandates on mobile homes will increase cost for families whose budgets are tight. Policy measures addressing the mobile home problem need to be based on a solid analysis.[2]

We explore several aspects of mobile home tornado fatalities in this paper. We examine the correlation between mobile homes and tornado risk across the US and find that mobile homes are not particularly concentrated in tornado prone states, but may be growing faster in the most tornado prone states. A concentration of manufactured housing in vulnerable areas cannot explain the high proportion of fatalities in mobile homes. We also break down tornado fatalities by state. The mobile home problem is concentrated in the Southeast, and just two states, Florida and Georgia, account for 30% of all US mobile home tornado fatalities. A difference in the severity of the mobile home problem across the country suggests possibly targeting risk reduction measures to areas of high risk. We also break down mobile and permanent home fatalities by the rating on the Fujita scale of tornado damage.[3] Mobile homes account for an even larger fraction of fatalities in less powerful tornadoes—those rated F1 to F3 on the F-scale—than fatalities overall. This is consistent with a greater vulnerability of mobile homes, as tornadoes that might only damage permanent homes could destroy mobile homes and kill occupants. Mobile home fatalities are also more likely to occur at night, and so the mobile home problem is related to the vulnerability of nocturnal tornadoes (Simmons and Sutter 2008a; Ashley et al. 2008). Fatalities do not occur at a higher rate at night in permanent homes, which suggests that the vulnerability of mobile homes at night results from residents being at home, not less effective warning transmission, consistent with Schmidlin et al. (2009).

[1] The term manufactured home refers to factory as opposed to site built homes, and the older term mobile homes refer to homes capable of being moved. In tornado research the terms are used interchangeably. We will use the more popular term mobile home instead of the industry's preferred term of manufactured home.

[2] De Alessi (1996) criticizes the unconvincing evidence of economic benefits from HUD's 1994 wind load provisions. Given the lower income of mobile home household, regulations that add costs without corresponding benefits impose a particularly heavy burden on relatively low income households, similar to a regressive tax.

[3] The Fujita scale rates tornado damage on a scale from F0 (weakest) to F5 (strongest). An F0 is a minimal tornado that causes light damage, while and F5 tornado causes "incredible" damage including well built homes swept off their foundations and cars thrown more than 100 m. A description on the Fujita scale and the Enhanced Fujita scale can be found at http://www.spc.noaa.gov/faq/tornado/f-scale.html.

2 Are mobile homes located in tornado prone states?

Mobile homes are not equally distributed across the United States (c.f. Ashley (2007); his 8.6). If manufactured homes happen to be more prevalent in tornado prone states, this could explain part of the mobile home problem. And growth of mobile homes in tornado prone states suggests that the problem will get worse in the future. Of concern for policy makers, a high concentration of mobile homes in areas of high risk could indicate that residents ignore tornado risk in housing choice, placing themselves at greater risk than desired. Tornadoes are low probability, high consequence events, and a considerable body of research finds that people often underestimate or ignore totally natural disasters and other low probability risks (Camerer and Kunreuther 1989; Meyer 2006). The mobile home problem may be a manifestation of low probability event bias, with residents neglecting tornado risk in housing choice.

To investigate these hypotheses, we examine the correlation between manufactured housing and tornado risk. We measure the prevalence of mobile homes three ways, mobile homes as a proportion of state housing units, the proportion of the population living in mobile homes, and mobile homes per square mile of state land area. All three are taken from the 2000 Census. We also consider the change in mobile homes as a proportion of housing units between 1990 and 2000, and the change in mobile homes per square mile of state land area. Tornado risk can be measured based on the incidence of either tornadoes or casualties. We use six different measures of tornado risk constructed by the authors from the Storm Prediction Center (SPC) tornado archive based on tornadoes between 1950 and 1999.[4] The first measure is the tornado rate, the annual number of tornadoes per 10,000 square miles of state land area. The second is the tornado probability, the total damage area of all tornadoes divided by state land area and divided by 50; this corresponds to an annual probability of damage. The tornado rate and tornado probability are also calculated based only on tornadoes rated F2 or stronger on the Fujita Scale. We use two measures of risk based on casualties, the fatality rate and injury rate, which are tornado fatalities and injuries per year per million residents. Note that injury totals are often unreliable relative to fatality counts. The casualty rates use the mean state population in millions from the six decennial censuses from 1950 to 2000.

Table 1 examines the relationship between tornado risk and mobile homes. We ranked the states by each measure of tornado risk, and Table 1 displays the proportion of mobile homes, the proportion of population living in mobile homes, and the change in the proportion of mobile homes for the five most and least prone tornado states.[5] The table also reports correlation coefficients between the measures of risk and mobile homes. Considerable differences in tornado risk exist across states, as one might expect. The mean tornado rate is 6.9 in the most prone states vs. 0.20 in the least prone, and the tornado probability is more than 3,000 times higher in the most prone states than the least prone states. The difference in incidence between the most and least prone states based on F2 and stronger tornadoes is larger than for all tornadoes. The top fatality states experience 2.3 fatalities and 32 injuries per year per million residents vs. 0 and 0.1 in the least prone states.

The stock of mobile homes is slightly larger in tornado prone states, as measured by rates or probabilities. The correlations are positive in all but one case but do not exceed +0.10 for any of these four measures of tornado risk except between the F2 and stronger

[4] The archive is available at http://www.spc.noaa.gov/archive.

[5] Except for the lowest fatality rate states, because eight states had no fatalities over the period, and all eight are included in our least vulnerable states.

Table 1 Tornado risk and mobile homes across states

	Rates, units	Mobile homes as proportion of housing units, 2000	Mobile homes per mile^2, 2000	Proportion of Pop'n in mobile homes, 2000	Change in Proportion of Mobile Homes, 1990–2000	Change in Mobile Homes per mile^2, 1990 to 2000
Tornado rate	Per 10,000 mile^2					
Highest	6.899	0.1067	4.574	0.0939	+0.00056	0.5888
Lowest	0.203	0.1014	1.665	0.0878	−0.0115	0.2180
Correlation		−0.017	+0.406	−0.035	+0.322	+0.294
Tornado probability						
Highest	0.0003874	0.1074	2.185	0.1061	0.0221	0.4905
Lowest	3.88E-06	0.0655	2.256	0.0518	−0.0047	0.1353
Correlation		+0.057	+0.064	+0.069	+0.473	+0.234
F2+ Tornado rate	Per 10,000 mile^2					
Highest	1.965	0.0999	2.934	0.0971	+0.0116	0.6160
Lowest	0.016	0.0636	1.991	0.0490	−0.0055	0.1142
Correlation		+0.036	+0.276	+0.036	+0.480	+0.309
F2+ Tornado probability						
Highest	0.000354	0.1074	2.185	0.0923	+0.0151	0.4905
Lowest	4.55E-07	0.1081	1.780	0.1186	−0.105	0.2485
Correlation		+0.009	+0.002	+0.100	+0.466	+0.215
Fatality rate	Per million residents					
Highest	2.3335	0.1327	3.070	0.1330	0.0221	0.8105
Lowest	0	0.0473	1.970	0.0381	−0.0046	0.0332
Correlation		+0.308	−0.020	+0.315	+0.538	+0.229
Injury rate	Per million residents					
Highest	32.25	0.1327	3.070	0.1330	0.0221	0.8105
Lowest	0.107	0.0472	1.926	0.0376	−0.0047	0.0328
Correlation		+0.326	+0.011	+0.332	+0.579	+0.281

These rates are based on totals over the years 1950–1999. The highest and lowest states are the five contiguous U. S. states with the highest and lowest tornado vulnerability on each measure, except for fatalities, where all 8 states with no fatalities are included as having the lowest fatality rates

tornado rate and mobile homes per square mile. The proportion of homes is somewhat larger in states with the highest vs. lowest tornado probability and F2 tornado probability, with a difference of around 4% of units. Similarly the proportion of population living in mobile homes is also only modestly associated with the tornado rate and probability and F2 and stronger tornado rate and probability. Mobile homes are more concentrated in high risk states as measured by the fatality or injury rate, with correlations of around +0.3 and mobile homes comprising 13% of units in the most vulnerable states vs. 5% of units in the states with the lowest casualty rates, although mobile homes per square mile are basically

uncorrelated with the casualty rates. A higher correlation between the casualty based measures of tornado risk and mobile homes than for the probability and rate based risk measures is not surprising, since casualties will be higher when more persons live in mobile homes for a given tornado rate.

These comparisons suggest that mobile homes might be somewhat more concentrated in states with greater vulnerability. But bivariate correlations do not account for other factors that might explain housing choice and the number of mobile homes in a state. In a cross-section regression analysis, Sutter and Poitras (2009) find that when controlling for other factors, higher tornado risk reduces the number of mobile homes in a state. The result is statistically significant, quantitatively substantial (a one standard deviation increase in tornado risk reduces mobile homes by 12–16%), and robust across different measures of tornado risk and econometric specifications. This result along with the modest difference in the proportion of mobile homes in the most tornado prone states in Table 1 suggests that a concentration of homes in tornado prone states does not explain the "mobile home problem."

We find stronger correlations between the four measures of tornado risk and the change in the proportion of mobile homes and the change in mobile homes per square mile, reported in the final two columns of Table 1. The correlations with the tornado rate and tornado probability are +0.22 and +0.48, and the change in the proportion of mobile homes is even more strongly correlated with casualty rates. The proportion of mobile homes increased by 2.2 percentage points in the most tornado prone states by all measures except the tornado rate, and declined in the least tornado prone states, by each measure of risk. Mobile homes are increasing in more tornado prone states, suggesting that the mobile home problem may get worse in the future.

3 Fatality locations by tornado F-scale rating

If mobile homes were not any more vulnerable to tornadoes than single family homes, the likelihood of a fatality when struck by a tornado should be equal for each type of housing. The breakdown of fatalities by F-scale provides evidence on this hypothesis. If each type of home were equally vulnerable to tornadoes, then the proportion of fatalities in mobile and permanent housings should be equal for tornadoes of different F-scale ratings. To investigate these hypotheses, we broke down fatalities over 1996–2007 by location for each F-scale category. The location is known for all but 2 of the 729 fatalities over these years. Forty-eight percent of these fatalities occurred in manufactured homes and 35% in permanent homes.

Figure 1 reports the proportion of fatalities in mobile and permanent homes by category. If we ignore the F0 category, with only four fatalities, the proportion of fatalities in mobile homes decreases and the proportion of fatalities in permanent homes increases at each category from F1 to F5. The percentage of fatalities in mobile homes declines from 70% for F1 to 60% for F2, 36% for F4 and 14% for F5. By contrast, the percentage of fatalities in permanent homes rises from 8% for F1 and 23% for F2 to 56% for F4 and 83% for F5. The distribution of fatalities across locations differs significantly from the national proportions for all F-scale categories except F0 and F4. Mobile home fatalities occur disproportionately in the F1, F2, F3 tornadoes, consistent with the greater vulnerability of these structures to less powerful tornadoes.

Table 2 displays the relative and cumulative frequency of fatalities by F-scale for mobile homes, permanent homes, and all fatalities. The strongest tornadoes result in the

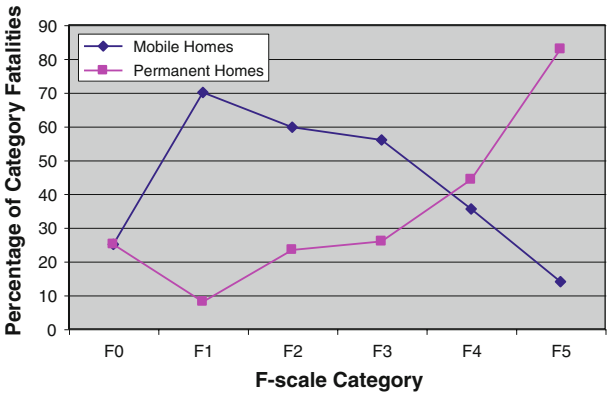

Fig. 1 Mobile home and permanent home fatalities by F-scale, 1996–2007

majority of fatalities: almost 93% of all fatalities occur in tornadoes rated F2 or higher, and over 75% of fatalities in F3 and stronger tornadoes. But mobile home fatalities are more uniformly distributed across F-scale categories, with more mobile home fatalities occurring in F1 than F5 tornadoes (10 vs. 4%). More than half of mobile home fatalities occurred in F3 tornadoes, and 82% occurred in tornadoes rated F3 or weaker. Permanent home fatalities, by contrast, are even more concentrated in strong tornadoes than fatalities overall; only 2% of these fatalities (5 total in 12 years) occurred in F0 or F1 tornadoes, while 87% occurred in tornadoes rated F3 or stronger, including 30% in F5 tornadoes. Comparison of the percentage of deaths in violent (F4 or F5) tornadoes illustrates this point. Half of one percent of tornadoes nationally over these years were violent (0.48%, 72), but they produced 32% of fatalities. Violent tornadoes accounted for only 18% of mobile home fatalities but 54% of permanent home deaths. Again mobile home fatalities occur much more frequently in weaker tornadoes.

4 The geographic distribution of mobile home fatalities

The geographic distribution of tornado fatalities has been examined by Boruff et al. (2003) and Ashley (2007). Overall tornado hazards and fatalities are concentrated in the Southeastern US, while tornadoes occur more frequently in the Plains states. We examine here the distribution of mobile home fatalities by state, which provides evidence on possible

Table 2 Tornado fatalities by location and F-scale, 1996–2007

F-scale	Mobile homes		Permanent homes		All fatalities	
	Relative proportion	Cumulative proportion	Relative proportion	Cumulative proportion	Relative proportion	Cumulative proportion
F0	0.003	0.003	0.004	0.004	0.005	0.005
F1	0.100	0.103	0.016	0.020	0.069	0.074
F2	0.211	0.313	0.114	0.133	0.170	0.244
F3	0.510	0.823	0.325	0.459	0.439	0.683
F4	0.140	0.963	0.239	0.698	0.189	0.872
F5	0.037	1.00	0.302	1.00	0.128	1.00

Table 3 Tornado fatalities by state and location, 1996–2007

State	Fatalities	Percentage in mobile homes	Percentage in permanent homes	Percentage in other locations	Chi-square test *p*-value
Alabama	88	44.3	43.2	12.5	0.228
Arkansas	56	46.4	28.6	25.0	0.236
Florida	75	70.7	10.7	18.7	< 0.001
Georgia	59	86.4	5.1	8.5	< 0.001
Illinois	20	35.0	5.0	60.0	< 0.001
Indiana	27	92.6	0.0	7.4	< 0.001
Kansas	29	20.7	58.6	20.7	0.009
Kentucky	11	72.7	18.2	9.1	0.264
Louisiana	18	72.2	5.6	22.2	0.031
Mississippi	17	23.5	58.8	17.6	0.086
Missouri	48	25.0	56.3	18.8	0.003
North Carolina	15	86.7	6.7	6.7	0.011
Ohio	11	27.3	36.4	36.4	0.176
Oklahoma	45	28.9	60.0	11.1	0.002
Tennessee	87	48.3	41.4	10.3	0.200
Texas	59	32.2	57.6	10.2	0.001
Total	729	48.1	35.0	16.9	

The Chi-square test is for a difference in the proportion of fatalities across the three categories in a state against the national distribution of fatalities

causes of the mobile home problem. Uniform vulnerability across the nation is consistent with the intrinsic vulnerability of mobile homes. On the other hand, a concentration of these fatalities in some parts of the country might suggest a role for warning performance, communication and dissemination of warnings, or other policy related factors. If the mobile home problem is regionally focused, a policy response might seek to target the high risk states.

Table 3 reports the break down of mobile and permanent home fatalities by state for 1996–2007. Only states with at least 10 fatalities are included in Table 3, since differences lack meaning when the total number of fatalities is too small. Sixteen states had at least ten fatalities; six states had 20 or fewer while the eight had 45 or more fatalities. The table also reports the *p*-value for a Chi-square test for a difference in the distribution of fatalities from the national distribution (the categories are mobile homes, permanent homes and other locations). The distribution of fatalities by location differs significantly (at the 0.10 level) from the nation for 11 states. Florida, Georgia, Indiana, Louisiana, and North Carolina have higher proportions of mobile home fatalities than the nation, while Kansas, Mississippi, Missouri, Oklahoma and Texas have more permanent home fatalities; Illinois has a disproportionately large proportion of fatalities in other locations. Of the states with a high proportion of mobile home fatalities, only Florida and Georgia also have a relatively high number of total fatalities, and thus these two states stand out as outliers for mobile home fatalities. Of the states with a high incidence of permanent home fatalities, Kansas, Oklahoma and Texas all had F5 tornadoes during the period, while Missouri had a number of deadly F3 and F4 tornadoes. In addition, Alabama, Arkansas and Tennessee, with large and approximately equal numbers of permanent and mobile home fatalities, also suffered

F4 or F5 tornadoes. Thus consistent with the distribution of fatality locations by F-scale, states with large numbers of permanent home fatalities had prominent killer violent tornadoes.

The mobile home problem thus has a strong regional component. Nearly 30% of all mobile home fatalities in the US occurred in Florida and Georgia, and the states with the third and fourth highest totals are also from the Southeast (Tennessee, Alabama). We can illustrate the disproportionate number of mobile home fatalities in Georgia and Florida by calculating the number of mobile home fatalities we would expect at national proportions given the number of fatalities in other locations. Florida had 22 fatalities in locations other than mobile homes, and nationally 51.9% of fatalities occurred in locations other than mobile homes. If these 22 fatalities were 51.9% of Florida fatalities, the state would have had 42 total fatalities, with 20 in mobile homes. Instead there were 53 mobile home fatalities in Florida, or 33 more than expected. Georgia had eight non-mobile home fatalities, and so based on this we would expect about seven mobile home fatalities; thus Georgia had 44 more mobile home fatalities than expected. Overall 58% of national mobile home fatalities occurred in states in the Southeast (Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina). Mobile home fatalities clearly contribute to the overall Southeast pull to tornado hazards documented by Boruff et al. (2003) and Ashley (2007).

What factors might explain the regional concentration of mobile home fatalities? One possibility might be the proportion of mobile homes in these outlier states. But neither Georgia nor Florida has a particularly high concentration of mobile homes, at 12.0 and 11.6% of housing units. By comparison, mobile homes are 10.7 and 9.0% of housing units in Oklahoma and Texas, two states with large permanent home fatality totals. The modest difference in the proportion of mobile homes also holds in a comparison of more states. Five states in Table 3 have a significantly higher proportion of mobile home fatalities and five with a significantly higher proportion of permanent home fatalities. Mobile homes comprise 11.9% of housing units in the first group and 10.2% in the second group. The difference in the population living in manufactured housing cannot explain such a large difference in the proportion of tornado fatalities by location.

The availability of tornado shelters in manufactured home parks is another possible factor. Many parks provide community tornado shelters as an amenity for residents. Schmidlin et al. (2001) surveyed manufactured home parks in 11 states regarding shelters, and 10 of the states in their study are also listed in Table 3.[6] The incidence of shelters parks is negatively correlated with the proportion of fatalities in mobile homes as we might expect, with a correlation of −0.52. Georgia, for instance, has the lowest reported percentage of parks offering shelters at 12%. Underground shelters in parks are also negatively correlated with the proportion of state fatalities in mobile homes, at −0.55.

The timing of tornadoes could also contribute to the regional variation. Tornadoes are significantly more lethal at night than during the day (Simmons and Sutter 2008a; Ashley et al. 2008). We examine the timing of mobile home fatalities in the next section, and find that the mobile home problem particularly stems from tornadoes after dark. Ashley (2007) documents the higher proportion of tornadoes in the Southeast at night; for the years of our examination (1996–2007), 13% of tornadoes in the seven Southeastern states occurred between Midnight and 6AM, compared with 6% of tornadoes nationally.

[6] The states with the percentage of parks surveyed reporting shelters and underground shelters, respectively were Alabama (15% shelters, 7% underground), Arkansas (35%, 15%), Florida (27%,0%), Georgia (12%, 5%), Illinois (22%, 8%), Indiana (22%, 10%), Kansas (80%, 60%), Mississippi (15%, 10%), Missouri (40%, 25%), and Oklahoma (76%, 66%).

Table 4 Characteristics of tornado and killer tornado paths

	All tornadoes	All killer tornadoes	All mobile home fatality tornadoes
Population density	149.8	181.4	142.2
Median income	$41,964	$40,386	$38,902**
Mobile homes as a proportion of housing units	0.1376	0.1639	0.1924**
Mobile home density	4.803	5.843**	6.571**
Other housing unit density	60.62	83.21**	61.27

Densities are per square mile. ** Statistical significance at the 0.10 level in a two-tailed test from the mean for all tornadoes

5 Characteristics of mobile home fatality tornadoes

We next search for differences between individual killer tornadoes, tornadoes resulting in mobile home fatalities, and all tornadoes. We use demographic and economic variables from the 1990 and 2000 Censuses for the counties contained in each tornado's path following Simmons and Sutter (2008a), updated for killer tornadoes between 2003 and 2007. A total of 15,056 state tornadoes occurred between 1996 and 2007; 264 tornadoes killed at least one person, and 145 resulted in at least one mobile home fatality.[7] Do the characteristics of the paths these tornadoes differ? The path variables are population density in persons per square mile, mobile homes as a proportion of county housing units, median family income (in 1999 dollars), mobile homes per square mile, and non-mobile home housing units (other units) per square mile. For tornadoes which struck more than one county the storm path variables are the average of the values for each county in that year. Annual values were imputed by linear interpolation from the census values.[8]

The paths of killer and mobile home fatality tornadoes are actually rather similar to the paths of all tornadoes. Table 4 displays the mean values of the path variables for the tornadoes in each category. Mobile home fatality tornado paths were less densely populated than all tornado paths (142 vs. 150 persons per square mile), poorer ($38,800 vs. $42,000) and had a higher proportion of mobile homes (0.192 vs. 0.138). Mobile homes per square mile are also higher for mobile home fatality tornadoes (6.6 vs. 4.8), a difference of about 35% of all tornadoes, but other units per square mile are virtually equal to all tornadoes (61.3 vs. 60.6). The differences in income, proportion of mobile homes, and mobile homes per square mile are statistically significant at the 0.05 level. The lower median family income for mobile home fatality tornadoes is probably related to the higher proportion of mobile homes; the median income of manufactured home households is about 70% of the national median income (Marshall and Marsh 2007). The paths of killer tornadoes as a group are more densely populated than the paths of all tornadoes (181 persons per square mile) and have slightly more mobile homes (due to the proportion of

[7] The data set is constructed based on the Storm Prediction Center tornado archive, which includes one entry for each state struck by a tornado. Thus tornadoes which struck more than one state have multiple entries, and thus the total of 15,056 tornadoes refers to the tornado segments within each state.

[8] Census annual population estimates and Small Area Income Estimates are used to construct population density and income variables for tornadoes since 2000. The proportion of mobile homes for tornadoes since 2000 is from the 2000 Census. The Consumer Price Index for all urban consumers (CPI-U) from the Bureau of Labor Statistics is used to adjust for inflation.

Table 5 Tornadoes and killer tornadoes by time of day, 1996–2007

	Proportion of all tornadoes	Proportion of all killer tornadoes	Proportion of all mobile home killer tornadoes
Midnight to 5:59AM	0.0611	0.1402	0.2138
6AM to 11:59AM	0.0830	0.0379	0.0621
Noon to 3:59PM	0.2674	0.2083	0.2000
4PM to 7:59PM	0.4590	0.3750	0.3034
8PM to 11:59PM	0.1294	0.2386	0.2207

The distribution of times of killer tornadoes and mobile home fatality tornadoes differ from the distribution of for all times in a Chi-square test ($p < 0.001$)

homes in the paths of mobile home fatality tornadoes), but virtually the same income. The population density difference translates into a significantly higher (at the 0.05 level) number of other units per square mile (83.2), while mobile homes per square mile are almost 20% higher than for all tornadoes (this difference is significant at the 0.10 level). The average population density of killer tornadoes that did not result in any mobile home fatalities (not reported in Table 4) is higher, at 229 persons per square mile.

We also examined the time of day of the tornadoes, creating five categories of overnight (Midnight to 5:59AM), morning (6AM to 11:59AM), afternoon (Noon to 3:59PM), late afternoon (4PM to 7:59PM) and late evening (8PM to 11:59PM, all times local). Table 5 presents the break down of tornadoes, killer tornadoes, and mobile home fatality tornadoes by time of day. Almost half (46%) of tornadoes occurred during the late afternoon, with 27% during the afternoon, 13% during the late evening, 8% in the morning, and 6% overnight. The proportion of killer tornadoes during the late evening and overnight periods is double the proportion of all tornadoes. About 38% of killer tornadoes occur during the late evening or overnight, as compared to 19% of tornadoes. And mobile home killer tornadoes are even more likely after dark, as 43% occur at these times. All killer tornadoes and mobile home fatality tornadoes are both less likely during the afternoon and late afternoon than all tornadoes. The differences in the distribution of killer tornadoes compared to all tornadoes are statistically significant (p-values of less than 0.001 in Chi-Square tests).

Simmons and Sutter (2008a) find in regression analysis that expected fatalities are 64% lower for a tornado during the day than overnight when controlling for other factors like the F-scale rating of the tornado, the issuing of a tornado warning, and storm path characteristics. Our analysis here suggests that this difference is largely due to mobile home fatalities. Figure 2 displays the distribution of fatalities in mobile homes and permanent homes by the day parts defined here. In total, one-third of mobile home fatalities occur during the overnight hours, vs. only 5% of permanent home fatalities; 78% of fatalities during these hours occur in mobile homes. By contrast, 54% (25%) of permanent (mobile) home fatalities occurred during the late afternoon, and half of all fatalities during these hours occurred in permanent homes. Note that not only are tornadoes more likely during the late afternoon, the strongest tornadoes (those rated F4 or F5) typically occur during this time as well. Regarding other times of the day, 21% of fatalities in each location occur in the late evening hours, while more mobile home fatalities occur during the morning (8 vs. 0.4%) and more permanent home fatalities occur during the afternoon.

Why do nighttime tornadoes kill so many residents of mobile homes? Two explanations can be distinguished. First, nocturnal tornadoes might result in more fatalities due to a difference in the warning process and warning response. Residents are probably less likely

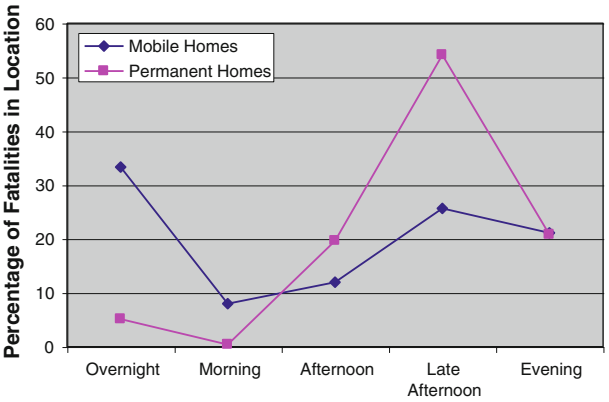

Fig. 2 Mobile home and permanent home fatalities by time of day, 1996–2007

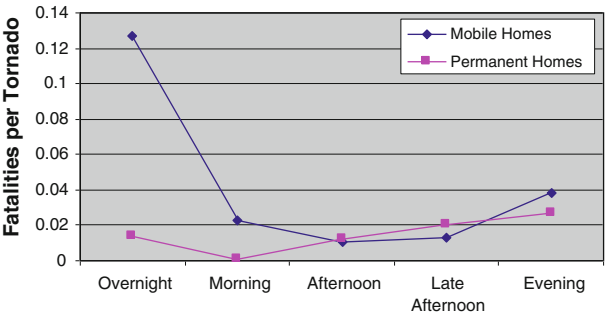

Fig. 3 Fatalities by location per tornado, 1996–2007

to receive a warning at night because they are asleep, and perhaps less likely to respond if they receive a warning if they cannot confirm the risk visually.[9] Second, mobile home fatalities at night might stem from these homes' vulnerability and residents just more likely to be home during the middle of the night. If warning response explains night time fatalities, we should see an elevated rate of fatalities in both mobile and permanent homes during the overnight hours. We calculate mobile and permanent home fatalities per tornado at the different times of the day to test this, and Fig. 3 displays the fatality rates at different times of the day. The fatality rate is higher for mobile homes during the overnight hours, 0.13 or one fatality per eight tornadoes, than for either location at any other time of the day, exceeding more than three times greater than the next highest rate for either location at another time of the day by more than a factor of three. By contrast, for permanent home fatalities per tornado during the overnight hours (0.014) is less than the rate for permanent homes in all tornadoes (0.017). The pronounced spike in the lethality of tornadoes overnight just for mobile homes suggests that the vulnerability may be due to the nature of mobile homes as opposed to warning response of nocturnal tornadoes. The fatality rate does not provide conclusive evidence, as it does not account for other factors like the F-scale distribution of tornadoes at different times of the day.

The fatality rates are consistent with Schmidlin et al.'s (2009) analysis of the response of manufactured home residents upon receiving a tornado warning. They found that 69% of

[9] Hammer and Schmidlin (2002) documented that many people fled the path of the May 3, 1999 Oklahoma City F5 tornado in their vehicles. Conceivably mobile home residents might be less likely to leave in cars at night due to an inability to see and thus move away from an approaching tornado.

residents did not take shelter upon receiving a warning, and almost one-third of those who responded did not choose an option that effectively reduced their vulnerability. Schmidlin et al. focused on warnings issued between 7AM and 11PM local time to ensure that respondents were home and received the warnings, but their finding—a lack of response to warnings—likely translates to nighttime tornadoes as well. This suggests that residents remain in their mobile homes if they are home, and since they are more likely to be home for overnight tornadoes, this could explain the vulnerability.

6 Conclusion

Observers and researchers have noted the mobile home problem for tornadoes. Analysis of manufactured home tornado fatalities between 1996 and 2007 reveals several characteristics of the problem and areas for future research. Stronger tornadoes are obviously more deadly than weak tornadoes, but an even larger proportion of fatalities occur in mobile homes in less powerful tornadoes, those rated F1, F2 or F3 on the Fujita Scale of tornado damage. It is only a slight exaggeration that F1 and F2 tornadoes are potentially lethal only for residents of mobile homes. The mobile home problem is also regionally focused, as 54% of mobile home fatalities occurred in the Southeastern U. S., and Georgia and Florida alone account for 30% of this total. Mobile home fatalities are especially likely to occur at night, particularly from Midnight to 6AM. Thus mobile homes might explain much of the lethality of nocturnal tornadoes, and the prevalence of night time tornadoes in the Southeast might explain the regional concentration of the mobile home problem.

Our findings have several implications for attempts to mitigate the mobile home problem. The regional component of the problem suggests that a targeted approach might be more effective than a nationwide response. The problem appears to stem from the vulnerability of mobile homes, combined with a lack of viable sheltering options. Mobile home park operators should play a role in providing sheltering for residents, and some do (Schmidlin et al. 2001). Yet many of the respondents in Schmidlin et al.'s (2009) survey lived in parks, and did not seem to have suitable sheltering available. And in any event, only around 40% of mobile homes nationally are located in parks. Building stronger mobile homes may be another option. In 1994 the Department of Housing and Urban Development (HUD) added wind load provisions to the HUD code for manufactured homes in hurricane exposed coastal areas. Simmons and Sutter (2008b) found that homes built to the wind load provisions performed much better in the February 2007 tornadoes in Lake County, Florida. Additional research would be necessary to determine if these results hold in other tornadoes, but 82% of mobile home fatalities occur in tornadoes rated F3 or weaker, so strengthening mobile homes so that residents can survive these tornadoes will go a long way toward addressing the mobile home problem.

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