8. Blown away: monetary and human impacts of the 2011 U.S. tornadoes

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1. Introduction

As 2011 began, the big news in the American sports world was the showdown between Auburn and Oregon for the national championship in college football. The big political story was the Tea Party, which had just helped Republicans regain control of the U.S. House of Representatives. In Hollywood, speculation was rife on who would win an Oscar. In other words, 2011 began as most years do. No one foresaw that the first five months of the year would reset the expectations of meteorologists, insurance companies, and the public regarding the toll tornadoes can impose on the U.S. today.

The decades leading up to 2011 convinced many that the tornado threat had been reduced to the point that 100 fatality tornadoes and 500 fatality years were in the past. After all, neither figure had been exceeded in the U.S. in over 50 years. The National Weather Service implemented a nationwide network of Doppler weather radars in the 1990s. Warning lead time doubled, and then almost doubled again, providing sufficient time for families to receive a warning and take shelter. Television stations used sophisticated graphics to cover tornadoes with ever-increasing accuracy. Street level tracking software allowed TV viewers to know the exact location of a tornado and how close it might get to their home. In this environment, a tornado that killed 10 or more people was national news and could grab the attention of the public for days and perhaps weeks. In 1999 one of the most powerful tornadoes ever documented struck a metropolitan area and resulted in 36 deaths, which while tragic, was only a fraction of the toll that might have been expected from a tornado like this at the start of the 20th century. The benchmark for what constituted a major tornado event was much different than 1974, when the 3-4 April "Super Outbreak" killed over 300 people. Things were different now, or so many people thought.

We begin by summarising the damages and fatalities from U.S. tornadoes in 2011. Next, we examine the tornado outbreak as it relates to the historical record. The next section looks at the role that extreme weather played, followed by a discussion of some of the vulnerabilities that are known to increase fatalities from tornadoes. We then consider what can be done to limit damages and fatalities from future tornado outbreaks. Finally, we discuss whether or not this was an event that can be expected to occur again and then we conclude.

2. A summary of tragedies

2.1. Damages

A final tally of the damages sustained from 2011 tornadoes is not complete but will set a record for inflation-adjusted property damage. Both Munich Re and the National Climatic Data Center estimate that overall damages will be about US$23 billion, with something over half that amount being insured. The breakdown by month is reported in Table 1.

Table 1: Breakdown of losses by month

Month	Insured losses	Total losses
April	US$11.bn	US$15.5bn
May	US$4.9bn	US$7.0bn
Total	**US$16bn**	**US$22.5bn**

Source: National Climatic Data Center.

Almost 60 per cent (US$9 billion) of the April losses occurred when over 300 tornadoes struck from the Midwest through the Mid-Atlantic on 27-28 April, with the worst of the outbreak centred on Mississippi, Alabama, Georgia and Tennessee. Most of the May damages occurred when an EF-5 tornado devastated Joplin, Missouri on the 22nd, setting a record for damages from a single tornado. An EF-5 tornado has wind speeds in excess of 200 miles per hour and is the highest rating on the Enhanced Fujita Scale used to rate the intensity of a tornado.[1]

The extensive losses caught many insurers off guard. By July, insurance claims already totalled almost US$7 billion and were expected to eventually exceed US$10 billion and perhaps as much as US$16 billion. In Alabama, Alfa Mutual, the second largest insurer in the state, has announced that it will not renew over 70,000[2] policies as well as increase rates by an average 20 per cent[3] for remaining policyholders to attempt to recover from its losses in the April outbreak.

A tornado is quite different from a hurricane. When a deadly hurricane comes ashore, the wind field is large and will affect thousands of homes. Hurricane damages result from wind, but also from water pushed onshore by the winds. A standard homeowners' policy does not cover rising water, but coverage is available through the National Flood Insurance Program. The National Flood Insurance Program was created by the U.S. Congress, with the National Flood Insurance Act of 1968 to offer residents in flood-prone areas a means to share flood risk via a quasi-insurance mechanism. Most banks require homeowners living in a flood plain to have flood insurance in order to obtain a loan for the home, but for many homeowners the coverage is voluntary. This issue became politically contentious after Hurricane Katrina, when Gulf Coast homeowners found that their insurance policy did not cover water damage.

A tornado is strictly a wind event with wind speeds that can exceed the most powerful hurricane. Damage can be extensive and violent tornadoes will completely destroy even the most permanent homes. But tornadoes are covered by a standard homeowner's policy

1 *http://www.spc.noaa.gov/faq/tornado/ef-scale.html*
2 *http://blog.al.com/live/2011/06/alfa_cuts_alabama_policies_tornadoes.html*
3 *http://blog.al.com/live/2011/09/post_128.html*

in the same way as other hazards such as fire.[4] Most homes are insured and any home with a mortgage is required to carry insurance. Insurance typically would cover repairs up to the insured value of the home. The homeowner would be liable for their deductible, which can vary from policy to policy. Nonetheless homeowners who have not updated their policies find themselves underinsured, thus having to use their own funds to complete repairs or rebuilding costs. Some coastal states have begun experimenting with discounts for construction features that limit damage.[5] The Insurance Institute for Business and Home Safety has its Fortified Home[6] programme to illustrate the types of construction practices that can limit wind damage.

Life insurance would compensate beneficiaries of those insured persons killed by the tornado. But tornado fatalities are a very small percentage of fatalities in the U.S., averaging between 50 and 60 per cent annually over much of the past 50 years. Even when this year is accounted for, the rate of tornado fatalities is exceedingly small compared to other mortal risks—for instance, auto accidents typically result in about 35,000 deaths per year.[7]

For qualified homeowners in Presidential disaster areas,[8] the Federal Emergency Management Agency (FEMA) provides some housing assistance, and loans are available through the Small Business Administration.[9] FEMA is also the lead agency in immediate recovery efforts. Damage to state infrastructure such as road and bridges is paid for from public funds at both the state and national level.

2.2. Fatalities

Damaged or destroyed structures can be rebuilt or repaired, but lives lost and shattered cannot be made whole. At this writing in December, the 2011 death toll stands at 552. Most of the deaths (97 per cent) occurred during April and May, with 86 per cent of these deaths from the 27-28 April outbreak across the Southeast and the Joplin, MO tornado on 22 May. Table 2 reports the fatality totals by month.

Table 2: Fatality total by month

Month	Deaths
February	1
March	1
April	361
May	179
June	4
August	2
November	6*

Source: Storm Prediction Center (*November numbers are preliminary).

4 *http://www.usatoday.com/money/industries/insurance/2011-04-28-tornado-insurance_n.htm*
5 *http://www.smartmoney.com/spend/real-estate/new-incentives-to-stormproof-your-home-1305608405674/*
6 Insurance Institute for Business & Home Safety, *www.ibhs.org*
7 *http://www.census.gov/compendia/statab/2012/tables/12s1103.pdf*
8 Upon receiving a request from a state governor, the U.S. President must declare a county to be a disaster area after the event for residents to qualify for these programmes.
9 *http://www.disasterassistance.gov/disaster-assistance*

The 2011 death toll is more remarkable when compared to recent history. Annual tornado fatalities averaged 57 for the 25 years prior to 2011, with the 100 fatality threshold exceeded only twice (in 1998 and 2008). Recent history certainly justifies a popular perception that tornadoes were not the threat they once were. Modern radar and spotter networks made warning the public seem like a science rather than an art (Smith, 2010). The past year reminds us that nature's awesome force often defies our best efforts to survive.

3. How does this year compare to previous extreme years?

3.1. Damage

As mentioned, 2011 set a record for damage and insured losses from tornadoes. But how does it compare to previous years, and particularly previous extreme seasons? Official statistics have been compiled by the Storm Prediction Center (SPC) in Norman, Oklahoma since 1950, so 60 years of records are available for comparison. We focus on damage over an entire season, as this more readily measures the impact on the insurance and reinsurance markets than individual tornadoes, given that the U.S. experiences over 1,000 tornadoes annually. Grazulis (1993) includes information on significant tornadoes prior to 1950 and includes damage estimates on some of these tornadoes. Brooks and Doswell (2001) use these records to make comparisons of selected tornadoes from before and after 1950. Any attempt at a systematic analysis of damage over a season must begin in 1950.

The damage data require several caveats. Natural hazards damage data are generally of questionable quality (Gall, Borden and Cutter, 2009; Downton, Miller and Pielke, 2005), limiting the precision of any comparisons or patterns we manage to identify. Damage estimates prior to 1996 were reported in order of magnitude intervals, with the lowest bin labelled "0" including tornadoes with zero damage and with unknown damage. Clearly some tornadoes with "0" damage must have resulted in damage based on casualties, path length, and F-scale[10] rating, and the missing damage reports serve to underestimate total damage for a season. The categories continue to the highest "9" with damage in excess of US$500 million. We use the mid-point of each category as the damage level for each tornado, as we have done in Simmons, Sutter and Pielke (2012). Since 1996 damage has been reported in dollar amounts. The SPC archive reports damage in current dollars, and so the damage amounts are adjusted for changes in the price level using the consumer price index.

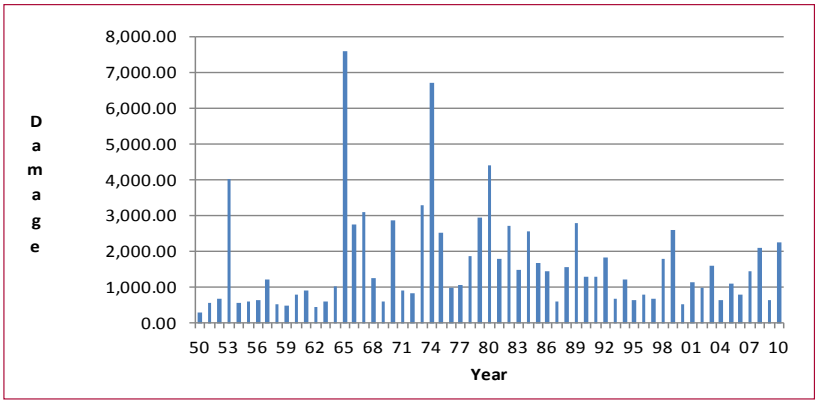
Inflation-adjusted damages have been rising over time for many types of natural hazards, for a number of different reasons. One cause has been increases in population and wealth. The U.S. is a more populated and wealthy nation now than in 1950, and damage is likely going to be higher now than in the past just because there are more people and property which might be in the path of tornadoes. Consequently, inflation-adjusted damage from the 1950s is likely incommensurable with damage in 2011, rendering the historical damage records of limited value. Natural hazards researchers have developed normalisations of damage for population and income or wealth changes (Pielke and Landsea, 1998; Brooks and Doswell, 2001). The normalisations adjust proportionally for changes in population and income, wealth or GDP, so if population doubles, damages are assumed to double as well. The normalisations provide some control for these determinants of damage

10 Fujita Scale in use until 2007. *http://www.spc.noaa.gov/faq/tornado/f-scale.html*

and allow a more meaningful comparison of current and historical damage figures. The normalised data provide a reasonable estimate of damage that might be expected if past tornadoes or tornado seasons occurred today.

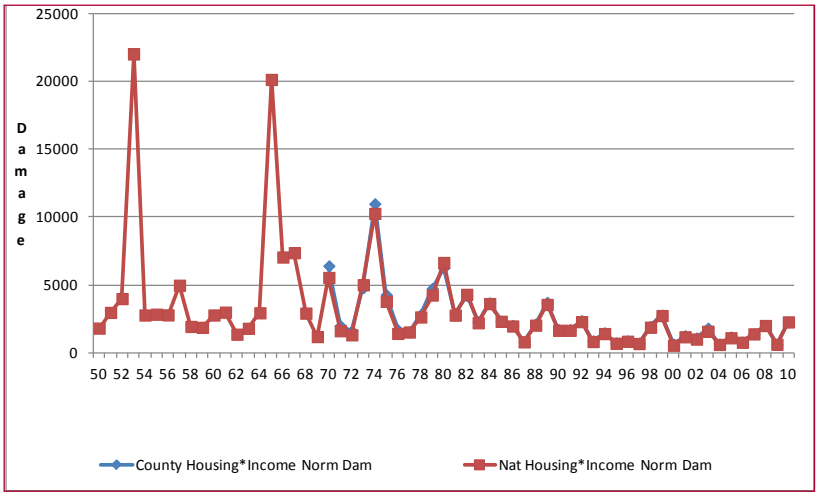
Figure 1 graphs inflation-adjusted damages for 1950-2010, while Figure 2 displays damage normalised for changes in housing and income, in addition to inflation. Both figures illustrate that 2011 was not unprecedented in terms of damage.

Figure 1: Annual damage in price level adjusted dollars, 1950-2010



Source: SPC Tornado Archive.

Figure 2: Annual damage normalised for changes in housing and income, national and county income/housing



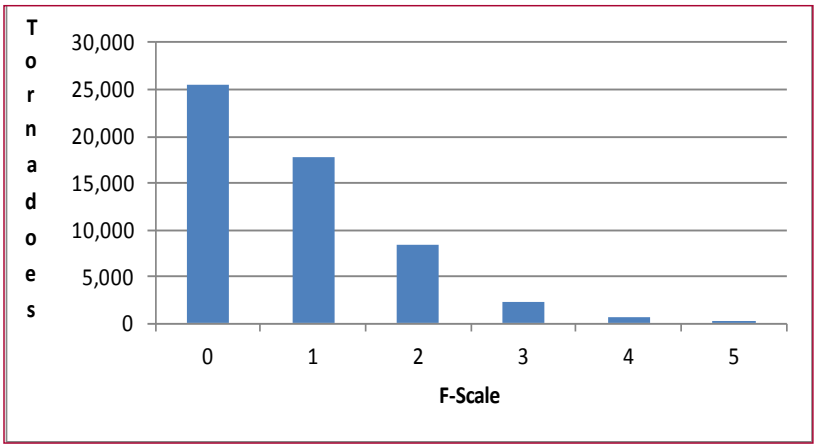
Source: SPC Tornado Archive.

Three previous seasons—1953, 1965 and 1974—now rival damage in 2011. Normalised damage exceeded US$20 billion in 1953 and 1965 and exceeded US$10 billion in 1974. The 1953 season provides perhaps the best historical comparison with 2011, as

much of the damage in 1965 and 1974 occurred in just one outbreak. Damage in 1965 is attributable to the Palm Sunday outbreak, while damage in 1974 occurred in the 2-3 April "Super Outbreak". 1953 had multiple damaging outbreaks in different parts of the country. One of the worst tornadoes of 1953 occurred in Worcester, MA, and ranked first in normalised damage until the Joplin tornado of 2011.

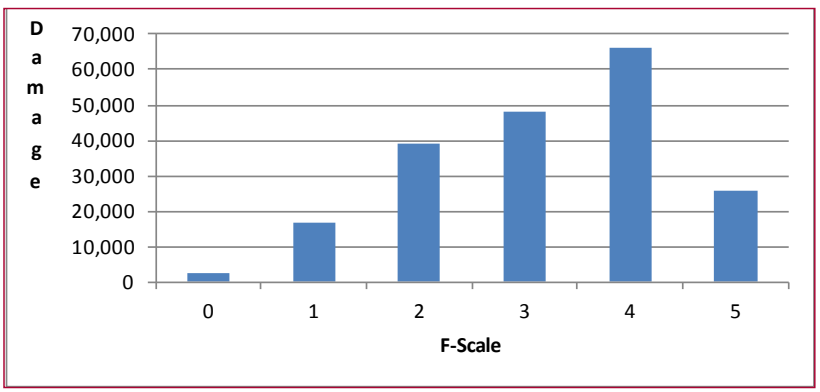
Damage is driven by the intensity of the tornado. While strong and violent (EF-2 and higher) tornadoes represent a small proportion of all tornadoes, they account for the vast majority of damage. Figure 3 shows the occurrence of tornadoes by F-Scale since 1950 while Figure 4 shows total normalised damage by F-Scale over this period.

Figure 3: All tornadoes by F-scale 1950-2010



Source: SPC Tornado Archive.

Figure 4: Housing/income normalized damage by F-scale 1950-2010



Source: SPC Tornado Archive.

The 2011 season featured an unusually large number of "long track strong/violent tornadoes" which contributed substantially to the observed damage. We will discuss these tornadoes further in a later section, but the longer a powerful tornado remains on

the ground, the more likely it is to strike populated communities and damage property. Damage is a function of the strength of a tornado, the length of its path, and what lies in its path. As we continue to expand urban areas in regions prone to tornadoes, the likelihood of significant damage will only increase when we have long track, powerful tornadoes.

3.2. Fatalities

2011 was the deadliest year for tornadoes since the start of official records with 552 fatalities, and tied with 1936 as the second most deadly year since 1875. Only 1925, the year of the Tri-State tornado, with 794 deaths, exceeds this year's toll.[11] The 500 fatality threshold has been eclipsed only seven times since 1875 (including 2011). Additionally, 2011 witnessed the deadliest single day (27 April, 320 fatalities) and deadliest single tornado (Joplin MO, 158 fatalities) since the start of official records in 1950.

As discussed above, most of 2011's fatalities occurred in two outbreaks, 27-28 April and the Joplin EF-5 tornado on 22 May. This is consistent with previous years where a handful of tornadoes produced a large proportion of fatalities. An extraordinary death toll requires a long track violent tornado tracking through an area with high population density. The 1953 season was something of an exception to this pattern, as 62 per cent of the 519 deaths came from three tornadoes in different parts of the country. A tornado in Waco, TX, in May killed 114 people, followed in June by 116 deaths in Flint, MI, and 90 in Worcester, MA, on consecutive days. Nonetheless 38 per cent of 1953's fatalities came from other tornadoes throughout the year. The other two years with the highest death tolls since 1950—1965 and 1974—had a higher proportion of deaths in one outbreak. In 1965, 260 of the 301 deaths that year (86 per cent) occurred in the Palm Sunday outbreak, while 80 per cent (290 of 366 fatalities) of 1974's deaths occurred on 3 April. So again we see that high death tolls occur when a violent tornado happens to strike a densely populated area.

4. What role did extreme weather play?

We now consider the role that extreme weather—the number and strength of 2011's tornadoes—played in the season's damage and fatalities. We use the SPC tornado archive as our reference in performing this analysis, which includes over 54,000 recorded tornadoes through 2010. But a quick look at the archive makes it clear that reports of tornadoes in later years were more common than in the early decades of the archive. This makes perfect sense as today we have ways of detecting tornadoes that did not exist 30 or 50 years ago. For instance the annual average of tornadoes during the 1950s was less than 500. The average over the last 20 years is about 1,300. Either tornadoes have become more common, or short track, weak tornadoes are more likely to be reported in recent years. The average number of reported tornadoes increased each decade until the 1990s and since then has remained fairly consistent. Of significance, powerful, long track tornadoes were likely accurately tabulated throughout the years of the record.

As discussed above, damage is largely a product of strong and violent tornadoes. Casualties are similarly concentrated in strong and violent tornadoes. Consequently the annual number of long track strong or violent tornadoes should explain much of the year-to-year variation in casualties and damage. We total the number of long track, strong

11 *http://www.norman.noaa.gov/2009/03/us-annual-tornado-death-tolls-1875-present/*

and violent (LTSV) tornadoes each year since 1950 and the fatalities and damage that occurred in these tornadoes. Specifically we count as an LTSV a tornado with a path length of five miles or more and an EF-scale rating of EF-2 or higher. An average of 89 LTSV tornadoes occurred annually between 1950 and 2010, with a standard deviation of 34. Most years should then see between 57 and 125 LTSV tornadoes; only five years had fewer than 57 and only seven more than 125 LTSV tornadoes. But the seven years with more than 125 LTSV tornadoes include 1974 and 1965. From 1950 to 2010, LTSV tornadoes accounted for 85 per cent of fatalities and 75 per cent of reported damage.

LTSV tornadoes also were important drivers of damage in the other seasons with the most normalised damage. Each of these years had a higher than average number of LTSV tornadoes: 103 in 1953, 144 in 1965, and 175 in 1974. And LTSV tornadoes accounted for at least 92 per cent of reported damage in each of these years.

How active was the 2011 tornado season? To date in 2011 there have been 1,836 tornadoes, which already exceeds the previous annual record of 1,736 in 2008. But of more interest is the number of LTSV tornadoes, which is 178 as of this date, in other words, double the annual average between 1950 and 2010.

As mentioned, only six times over 1950-2010 did the annual total LTSV tornadoes exceed 125, which is one standard deviation greater than the annual mean. The 2011 total also exceeds the highest total observed over this period, 175 in 1974. The 2011 total exceeds the 61 year average by two standard deviations. This suggests that the 2011 season was about a 20 year event for LTSV tornadoes.

LTSV tornadoes alone do not explain death tolls. Examples exist of years with above average numbers of LTSV tornadoes but modest fatality totals and deadly years with few LTSV tornadoes. For instance, 1982 had 142 of LTSV tornadoes, one of the highest totals since 1950, and only 64 deaths, while 1952 had 63 LTSV tornadoes and a death toll of 230, one of the deadliest years over the period. Over 89 per cent of deaths in 1952 were in LTSV tornadoes, demonstrating that the exact paths, timing, and other factors of a year's most dangerous tornadoes matter as well.

5. What role did societal vulnerabilities play?

Extreme weather appears to be the largest contributor to the historic damage and death tolls in 2011. Research (Simmons and Sutter, 2011) has highlighted several factors increasing the lethality of tornadoes casualties, including 1) mobile homes, 2) timing, and 3) region of the U.S. How much of a factor did these vulnerabilities play in the societal impact of the 2011 tornado season?

Manufactured or mobile homes have long been identified as vulnerable to tornadoes. While few site built homes can withstand the winds of a violent tornado, mobile homes are vulnerable to severe damage from weaker tornadoes that may cause only modest or minor damage to a permanent home. Mobile homes comprised 7.6 per cent of the U.S. housing stock in the 2000 Census, but over the years 1995-2010, 43 per cent of tornado fatalities have occurred in mobile homes. So a community with a larger proportion of mobile homes is likely to suffer more fatalities from a given tornado. How much of a role have mobile homes played in the 2011 death toll? Table 3 reports the location of 2011 tornado fatalities.

Table 3: Location of 2011 tornado fatalities

Mobile homes	Permanent homes	Vehicles	Permanent buildings	Outdoors	Unknown	Total
122	209	34	85	8	94	552

Source: Storm Prediction Center.

The location of 94 of the year's 552 fatalities is currently unknown, and determination of where these fatalities occurred could affect inferences about 2011's fatalities. Mobile homes accounted for a smaller proportion of fatalities in 2011 than over the past 25 years. To date 122 deaths are known to have occurred in mobile homes, 22 per cent of all fatalities and 27 per cent of known location fatalities. Even if we assume that all 94 of the unknown location fatalities were in mobile homes, only 39 per cent of 2011 fatalities would have occurred in mobile homes, which is still less than in recent experience. Based on data from the 2010 American Community Survey for housing, mobile homes comprised an average of 16.8 per cent of the housing stock of the path counties from this year's killer tornadoes, which exceeds the proportion of mobile homes nationally. This certainly suggests that the mobile home problem was not responsible for as large a proportion of fatalities in 2011 as in recent years. Mobile homes comprise such a disproportionate share of fatalities because of fatalities in weak and strong tornadoes (EF-3 or less). The likelihood of death in EF-5 tornadoes is approximately equal for permanent and mobile home residents. The number of violent tornadoes in 2011 explains why the proportion of deaths in mobile homes was relatively low.

Timing is an important determinant of tornado fatalities. Tornadoes during the middle of the night, say 2:00 a.m., are not surprisingly more deadly than comparable tornadoes in the middle of the afternoon; everything else equal, expected fatalities are about 75 per cent higher for night-time tornadoes relative to a comparable tornado in the afternoon. The warning response is likely responsible for this difference, as people will be asleep and less likely to receive a warning for a night tornado. But tornadoes after dark do not explain 2011 fatalities. Of the 59 killer tornadoes to date in 2011, only six occurred between midnight and six a.m., with a total of seven fatalities. Nocturnal tornadoes are a known threat and research is needed to address this vulnerability, but it does not explain the 2011 death toll.

The final societal vulnerability that we address is regional differences in fatalities. Fatalities, like tornadoes, are regionally concentrated. The incidence of fatalities is best compared across states as rates per million persons to control for differences in population. Table 4 (adapted from Simmons and Sutter, 2011) reports the 10 states with the highest annual fatality rates over the years 1950 to 2007. For comparison, the U.S. annual fatality rate was 0.4 per million over this period. The states with the highest fatality rates are (in order) Mississippi, Arkansas, Alabama, Kansas, Oklahoma, Tennessee, Indiana, Missouri, Louisiana, and Texas. Table 4 also reports each state's fatality total in 2011.

The worst tornadoes of 2011 occurred in all the wrong places as eight of the states with the highest fatality rates account for 90 per cent of 2011 fatalities. If the outbreaks happened in other parts of the country, would we have seen fewer fatalities? Fatality rates do not allow a conclusive answer because many other factors affect casualties, but regression analysis suggests that expected fatalities are about 25 per cent higher in southeastern

states than elsewhere, controlling for a range of tornado and path characteristics. Thus regional vulnerabilities affected 2011 fatalities, particularly in the deadly April outbreaks.

Table 4: Incidence of fatalities across states as rates per million persons

	Fatality rate	2011 fatalities
Mississippi	2.8797	32
Arkansas	2.6966	12
Alabama	1.7230	242
Kansas	1.7014	3
Oklahoma	1.6373	14
Tennessee	1.0727	33
Indiana	.8301	0
Missouri	.7311	158
Louisiana	.7041	1
Texas	.6883	0
Total		**495**

Source: Storm Prediction Center.

6. Can we limit damage and casualties from future outbreaks?

The toll of the 2011 tornado season on persons and property has policymakers, insurers and residents asking the obvious question, "What can we do to prevent more years like 2011?" We turn to this question here.

6.1. Damages

We start with the question of property damage. It would seem that the answer is not much, given the power of tornadoes. While it is possible to engineer a structure to withstand the forces of even a violent tornado, the cost of doing so is prohibitive, particularly for residential construction. Wind engineers have focused on strengthening a small area within a home to save lives. While trying to build homes to withstand violent tornadoes is practically impossible, building techniques designed for hurricanes can help reduce tornado damage. Although violent tornadoes might still destroy strengthened homes directly in their path, we recall that 75 per cent of tornadoes are weak, or rated EF-0 or EF-1 on the Enhanced Fujita Scale. Winds in an EF-1 tornado are estimated to be 110 mph or less, which is within the range of design wind speeds for building codes in coastal areas prone to hurricanes. And all homes in the path of a violent tornado will not experience EF-4 or EF-5 damage. The EF-scale rating for a tornado is by convention based on the maximum damage along the path, and so some portion of the path of a violent tornado will only experience a weak or strong tornado. And not all structures in the path of a tornado at EF-5 strength will suffer EF-5 damage—structures on the edge of a tornado, which might be perhaps a mile wide, might suffer only EF-0 or EF-1 damage. Not every home in the path of a twister is going to be flattened. A study in the aftermath of the April 2011 Tuscaloosa, AL EF-4 tornado documented substantial damage that could have been avoided with improved building techniques.

Builders can adopt construction practices like threaded bolts in the foundation to secure exterior base plates, brackets or hurricane straps to attach exterior walls to roof joists, and use of oriented strand board (OSB) sheathing to increase the structure of the exterior walls. These are some of the same measures included in strengthened wind zone building codes. Some builders are already incorporating such techniques. After the May 1999 tornado outbreak, one Oklahoma City area home builder[12] sought advice from civil engineers at the University of Oklahoma on how to better protect homes from tornadoes. The builder adopted some of the above practices and estimated that the additional cost was about US$500 per home in the early 2000s.

That we can build more tornado and wind resistant homes does not demonstrate the economic case for doing so. An additional cost of US$500 per home might seem modest, but the probability of any home being in a tornado path over its lifetime is low, even in tornado-prone states. While extensive research has been done on damage reductions for strengthened construction in hurricane or straight-line winds, tornado winds produce very different stresses on structures. The data necessary to conduct a rigorous benefit/cost analysis are not available. But available evidence suggests that strengthened construction may be economically viable. Sutter, DeSilva and Kruse (2009) use insurance losses and tax assessor loss estimates from the May 1999 Oklahoma City tornadoes to estimate damage per home by F-scale category. They find that if strengthened construction can reduce losses by one F-scale category, that is, make a home struck by a F2 tornado be damaged as if it had been struck by an F1 tornado, then strengthened construction may be worth the cost, at least in the most tornado-prone states. In addition, strengthened construction should reduce casualties, which would provide additional benefits. Additional research would be needed to establish this point conclusively, but improved construction techniques may help reduce damage and insured losses.

6.2. Fatalities

The National Weather Service has undertaken many steps to help protect the U.S. public from tornadoes over the decades. Important measures include the issuing of formal warnings for tornadoes after 1953, ongoing educational efforts, and the installation of a nationwide network of Doppler weather radars in the 1990s. Warnings now provide sufficient lead time allowing residents to take cover, and permanent homes offer adequate protection from most tornadoes. Sheltering in a closet or bathroom, however, is of limited effectiveness when a violent tornado wipes a home's foundation clear. Since constructing an entire home to withstand an EF-5 tornado is cost prohibitive, engineers have designed "safe rooms" and below ground tornado shelters that can protect residents at a much lower cost. A "safe room" looks like a normal closet or small room but is constructed with walls that will survive a violent tornado. Residents can safely shelter in this room and expect to survive.

Tornado "safe rooms" gained national attention in the aftermath of the 1999 tornado outbreak in central Oklahoma when a family sheltered in their safe room while the rest of their neighbourhood was destroyed.[13] The attention motivated FEMA and the state of Oklahoma to offer subsidies to residents who wanted to install a safe room or outdoor

12 *http://www.homecreations.com/index.cfm?id=1*
13 *http://www.usatoday.com/weather/resources/safety/saferoom.htm*

shelter. The programme was so popular it was oversubscribed (Merrell, Simmons and Sutter, 2002) and spawned other programmes across the region.

Public money has many competing uses, and the funds used to subsidise shelters or safe rooms could be spent on other programmes, including those designed to save lives. Thus, although protecting residents from tornadoes is a worthwhile goal, continued funding of such programmes should only be based on a rigorous benefit/cost analysis. And such an analysis is not favourable to shelters in permanent homes (Simmons and Sutter, 2011). To see this, consider the case of Alabama, which suffered 242 fatalities in 2011. Let us assume that shelters could be provided at a cost of US$2,000 per home. To eliminate permanent home tornado fatalities, shelters would essentially need to be built into all homes in the state. The total cost of shelters is the cost (US$2,000) multiplied by the number of single family homes in the state, estimated at 1.31 million in 2010, for a total cost of US$2.6 billion. Alabama experienced 242 fatalities in 2011, but this thankfully does not occur every year. Since 1950 Alabama has averaged about 10 fatalities per year. Nationally just over 30 per cent of fatalities occur in permanent homes, so shelters in all permanent homes could save 3.1 lives per year. If we assume a 50 year useful life of a shelter and apply a discount rate of 3 per cent, the cost per life saved is almost US$32 million. This exceeds what could be considered an acceptable range for "value of life" (Viscusi and Aldy, 2003).[14] Even in the most tornado-prone states, tornado shelters do not appear to be good public policy investments.

Mobile homes are much more vulnerable to destruction by tornadoes, and the fatality rate for residents of these homes is about 10 times greater than for permanent homes. Because 43 per cent of fatalities occur in mobile homes, shelters in all mobile homes in the state might save 4.3 lives per year and the cost would be much lower because there are only an estimated 243,000 mobile homes in Alabama. The cost per life saved falls to a little over US$4 million, which suggests that government assistance, if offered, should be directed to mobile homes.

Private purchase of shelters is a different issue, however. There is some evidence that shelters increase the value of residential properties (Simmons and Sutter, 2007). This fact, plus the peace of mind that owning a shelter may bring, could encourage many to build a shelter or safe room in their home. But currently, there are few financial incentives for someone to install a safe room such as discounts on insurance rates, and even then the benefit-cost ratio may still be questionable.[15]

7. Can it happen again?

Since 1950, total normalised tornado damage has exceeded US$20 billion three times (1953, 1965, 2011) and US$10 billion one other time (1974). Twice (1953 and 2011) fatalities have exceeded 500. Normalised damage provides a way to make damage from past years comparable to contemporary losses and thus estimate a frequency of loss exceedance. The past suggests that we might expect a US$10 billion damage year once every 15 years and a US$20 billion damage year once every 20 years. Sixty years is not a long enough data series to estimate 100 or 200 year aggregate loss levels. An alternative approach could use GIS (Geographic Information Systems) software to project tornado

14 For a more detailed discussion see Simmons and Sutter (2011).

15 *http://www.smartmoney.com/spend/real-estate/new-incentives-to-stormproof-your-home-1305608405674/*

damage paths onto different areas to estimate the number of buildings which might be damaged or destroyed in a worst-case long track violent tornado. Wurman *et al.* (2007) have done this for major U.S. metropolitan areas and a long track EF-5 tornado which maintained close to its maximum intensity across its path could damage or destroy 40,000 or more buildings in many metro areas. By comparison, the 2011 Joplin tornado damaged or destroyed about 7,500 buildings. Consequently a single tornado resulting in US$10 billion or even US$20 billion cannot be ruled out.

Location is crucial for tornado damage and casualties. If the Joplin tornado had occurred just 20 miles north of its actual path, it would have struck a primarily rural area and would not have produced the greatest property loss of any tornado on record or the highest death toll in over 60 years. But if the path continued to shift north and not 20 miles but 160 miles, the tornado would have struck Kansas City and the damage and casualties could easily have been worse. Damage and casualties depend on exactly where the tornadoes occur, and thus a matter of luck. One factor which appears to increase the likelihood of losses like 2011 in the future is population growth. Since 1950, the population in the 10 states in Table 4 with the highest tornado fatality rates has more than doubled. While a growing population increases the likelihood that a tornado will strike populated areas, the more important factor here is likely suburbanisation. Urban areas have population densities over 1,000 persons per square mile, which can be 100 (or more) times greater than the population density of rural areas. A doubling of population which doubles population density everywhere over 50 years will have little effect on impacts relative to the variation from year to year due to violent tornadoes striking urban or suburban areas. Population and suburban growth together increase the likelihood that tornadoes will strike subdivisions and damage or destroy hundreds or thousands of homes.

8. Conclusion

Society has been tragically reminded that nature is a sometimes violent and unforgiving force. This year tornadoes have caused more than US$20 billion in damages and claimed 552 lives. While we can reduce casualties from more frequent weaker tornadoes, the options are much less attractive for people caught in the path of the numerous violent tornadoes which struck the U.S. in 2011. The same more or less applies to damages, as mitigation will not be economically attractive for the relatively rare violent tornadoes.

The 2011 tornado season resulted in the largest property loss of any tornado season on record and has raised concerns for insurers about tornadoes as possible catastrophic events. The challenge for public officials and for insurers is to find ways to model the return frequency of these events to allow for the necessary preparations and to ensure sufficient claim reserves. Normalised tornado damage, which provides a way to adjust past losses for changes in population and wealth, suggest that the 2011 season is not without precedent, but rather comparable to at least two prior years: 1953 and 1965. Thus we can reasonably expect to see a repeat of the insured losses from this year at some point in the future.

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