Weather, Traffic Accidents, and Exposure to Climate Change

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Climate change may affect traffic accidents.

- Interactions with existing risks:
  - Increased rainfall makes driving difficult.
  - Extreme heat may cause cognitive impairment.
- Voluntary exposure
  - Heat may draw more pedestrians, bikers, and motorcycles.
  - Ultra-light duty (ULD) modes are vulnerable in crashes.

A full accounting of welfare requires

- Direct Costs
  - Changes to accidents
- Defensive Expenditures (Harrington and Portney, 1987)
  - Avoided trips when conditions are bad
  - Will happen when existing risk is aggravated
- Voluntary Exposure Benefits
  - Benefits of spending time outdoors using ULD modes
  - May partially or fully offset direct costs
- We find voluntary exposure offsets at least 1/3 of fatality costs.

Broader implications

- Direct costs of climate change are often most salient.
  - Death and injury well documented in official statistics
- Defensive Expenditures are occasionally documented in terms of spending on health care costs.
- Voluntary exposure benefits are often difficult to measure and quantify. Our work is the first to study to measure this behavior.

Why study traffic accidents specifically?

- Traffic fatalities are the leading cause of death for those 4 to 35 in U.S.
- Worldwide 1.24 million fatalities annually
- Costly: Value of a Statistical Life of $9.1 million per person
- We can measure defensive expenditures and voluntary exposure.
  - Defensive expenditures: Fewer trips
  - Voluntary exposure: More trips
- We can quantify defensive expenditures and voluntary exposure benefits: the price of trip is a product of the probability of a fatality per trip and the value of a statistical life.

Data

- State Data System
  - Census of police-reported accidents, injuries and fatalities.
  - 6.7 million state-county-year-day counts for 20 states.
- Waves of the National Household Travel Survey
  - Daily trip count, miles per trip for ULD, LDV and public transit
  - 283,126 household-day observations across 1990, 1995, 2001 and 2009 surveys.
- Weather
  - Historical weather from National Climatic Data Center
  - Predicted weather from Hadley 3 A1B scenario

Methodology

- Poisson Count Model for fatalities, accidents, household trip count and miles per trip
- $f(y_{d,c}|\boldsymbol{x_{d,c}}) = \frac{e^{-\mu}\mu^{-y_{d,c}}}{y_{d,c}!}, \quad y_{d,c} = 0,1,2,\ldots$
- $E(y_{d,c}|\boldsymbol{x_{d,c}}) = \mu = exp\left(\begin{matrix}\sum_{j=1}^{8}\alpha^j T_{d,c}^j + \sum_{j=1}^{5}\beta^j R_{d,c}^j + \sum_{j=1}^{5}\gamma^j S_{d,c}^j \\ +\sum_{j=1}^{8}\alpha_{-1}^j T_{d-1,c}^j + \sum_{j=1}^{5}\beta_{-1}^j R_{d-1,c}^j + \sum_{j=1}^{5}\gamma_{-1}^j S_{d-1,c}^j\end{matrix}\right) + \theta_{scym} + z'_{d,c}\delta)$
- T: 10 degree temperature bins. R: Rainfall bins. S: Snowfall bins. Lags of weather.
- θ_{scym} controls for state-county-month year
- Z: in travel demand regression, additional household characteristics

Table 3: Poisson Regression of Incidents on Weather Variables

	Fatalities		Accidents	Injuries
	LDV Crashes	ULD Crashes		
Contemporaneous + Lagged Temperature				
<20 F	-0.143***	0.014	-0.605***	0.097***	0.000
	(0.029)	(0.055)	(0.117)	(0.022)	(0.022)
20-30 F	-0.117***	0.007	-0.632***	0.028*	-0.041***
	(0.026)	(0.026)	(0.074)	(0.017)	(0.015)
30-40 F	-0.089***	0.005	-0.413***	-0.031***	-0.070***
	(0.019)	(0.015)	(0.077)	(0.009)	(0.007)
40-50 F	-0.063***	-0.012	-0.143***	-0.023***	-0.044***
	(0.014)	(0.016)	(0.031)	(0.005)	(0.004)
60-70 F	0.055***	0.021**	0.128***	-0.005	0.020***
	(0.009)	(0.009)	(0.018)	(0.005)	(0.004)
70-80 F	0.069***	0.015	0.176***	-0.011*	0.022***
	(0.015)	(0.014)	(0.030)	(0.006)	(0.005)
>80 F	0.095***	0.054***	0.177***	-0.010	0.016**
	(0.015)	(0.020)	(0.027)	(0.008)	(0.007)
Rainfall					
0-0.1 cm	-0.029***	-0.001	-0.080***	0.023***	0.014***
	(0.009)	(0.010)	(0.029)	(0.004)	(0.005)
0.1-0.5 cm	-0.049***	-0.006	-0.176***	0.071***	0.058***
	(0.011)	(0.012)	(0.023)	(0.005)	(0.005)
0.5-1.5 cm	-0.059***	0.006	-0.201***	0.107***	0.088***
	(0.015)	(0.015)	(0.035)	(0.007)	(0.007)
1.5-3 cm	-0.086***	-0.040**	-0.302***	0.147***	0.119***
	(0.016)	(0.020)	(0.052)	(0.011)	(0.010)
>3 cm	-0.048	0.024	-0.227**	0.188***	0.144***
	(0.032)	(0.044)	(0.096)	(0.015)	(0.017)
Snowfall					
0-0.1 cm	0.027*	0.054***	-0.017	0.022***	0.007
	(0.016)	(0.020)	(0.062)	(0.007)	(0.008)
0.1-0.5 cm	0.073***	0.083***	-0.170***	0.098***	0.078***
	(0.020)	(0.023)	(0.060)	(0.010)	(0.007)
0.5-1.5 cm	0.130***	0.158***	0.028	0.230***	0.189***
	(0.028)	(0.029)	(0.073)	(0.010)	(0.010)
1.5-3 cm	0.155***	0.143***	-0.032	0.354***	0.281***
	(0.023)	(0.042)	(0.104)	(0.012)	(0.010)
>3 cm	0.040	-0.032	-0.117	0.433***	0.259***
	(0.044)	(0.047)	(0.094)	(0.014)	(0.022)
Fixed Effects					
State-county-year-month	Y	Y	Y	Y	Y
Num. Obs.	3,117,797	2,829,908	406,051	6,665,499	5,067,561

Table 5: Travel Demand

	Light Duty Trip Count	Light Duty Miles per Trip	Ultralight Duty Trip Count	Ultralight Miles per Trip	Public Transit Trips
Contemporaneous + Lagged Temperature					
<20 F	-0.051**	-0.007	-0.292***	-0.384*	-0.281**
	(0.023)	(0.071)	(0.060)	(0.202)	(0.125)
20-30 F	-0.037**	-0.025	-0.144***	-0.399***	-0.199**
	(0.016)	(0.050)	(0.039)	(0.141)	(0.101)
30-40 F	-0.026**	0.019	-0.095***	-0.302*	-0.036
	(0.010)	(0.028)	(0.033)	(0.161)	(0.051)
40-50 F	-0.003	-0.041**	-0.033	-0.004	-0.066
	(0.007)	(0.018)	(0.022)	(0.092)	(0.046)
60-70 F	-0.007	0.028	0.027	-0.027	0.048
	(0.009)	(0.020)	(0.020)	(0.071)	(0.060)
70-80 F	-0.009	0.029	0.006	-0.057	0.028
	(0.008)	(0.034)	(0.031)	(0.114)	(0.063)
>80 F	-0.037**	0.011	0.021	0.093	-0.144
	(0.016)	(0.052)	(0.042)	(0.125)	(0.103)
Rainfall					
0-0.1 cm	-0.012*	0.006	-0.007	-0.074	0.001
	(0.006)	(0.016)	(0.019)	(0.046)	(0.051)
0.1-0.5 cm	-0.005	-0.050***	-0.067***	-0.154***	0.027
	(0.008)	(0.018)	(0.019)	(0.058)	(0.039)
0.5-1.5 cm	-0.007	-0.009	-0.091***	-0.171**	0.010
	(0.007)	(0.030)	(0.018)	(0.066)	(0.060)
1.5-3 cm	-0.031**	0.074*	-0.144***	-0.602***	0.036
	(0.012)	(0.039)	(0.040)	(0.130)	(0.062)
>3 cm	-0.034*	0.067	-0.087	-0.036	0.214*
	(0.020)	(0.106)	(0.059)	(0.287)	(0.124)
Snowfall					
0-0.1 cm	-0.003	0.034	0.025	-0.088	0.068
	(0.015)	(0.048)	(0.044)	(0.095)	(0.055)
0.1-0.5 cm	-0.017	0.021	-0.127***	0.089	-0.054
	(0.013)	(0.041)	(0.037)	(0.090)	(0.090)
0.5-1.5 cm	-0.012	-0.013	-0.151***	0.003	-0.155
	(0.020)	(0.057)	(0.044)	(0.120)	(0.079)
1.5-3 cm	-0.075**	0.047	-0.105	0.194	-0.034
	(0.030)	(0.102)	(0.068)	(0.136)	(0.114)
>3 cm	-0.160***	0.032	-0.104	0.081	0.005
	(0.035)	(0.079)	(0.077)	(0.146)	(0.141)
Fixed Effects					
State-county-year-month	Y	Y	Y	Y	Y
Household Controls	Y	Y	Y	Y	Y
Num. Obs.	261,667	223,659	228,144	53,437	177,987

Results

- Strong positive relationship between temperature and fatalities
  - Nearly all of effect is due to ULD accidents
  - Pedestrians, Bikes and Motorcycles used despite high risk
  - Rain decreases fatalities (behavioral changes to reduce fatalities)
  - Snowfall increases accidents.
- Accidents decrease as temperatures warm.
  - Precipitation increases accidents.
- Travel Demand
  - Light Duty Vehicle travel: mostly no response, small avoidance for hot days
  - ULD is positive relationship with temperature: voluntary exposure

Change in Fatalities with Climate Change

Panel A. 2090 Changes, Quantile Based Correction Method

	Fatalities						
	Full Sample	LDV	ULD	LDV Trips (in billions)	ULD Trips (in millions)	Accidents	Injuries
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Change in 2090 due to Temperature	849	253.6	634.9	-0.93	467	-28,019	13,022
	[659, 1045]	[49, 469]	[524, 737]	[-2.17, 0.24]	[47, 862]	[-48,368, -7,481]	[6171, 19609]
Change in 2090 due to Rainfall	-101	-2.7	-89.7	-0.23	-45	25,272	6,800
	[-138, -65]	[-43, 40]	[-127, -56]	[-0.39, -0.08]	[-99, 7]	[21,683, 28,980]	[5367, 8266]
Change in 2090 due to Snowfall	-152	-162.3	41.8	0.48	150	-72,137	-19,699
	[-190, -116]	[-202, -122]	[12, 74]	[0.27, 0.68]	[88, 212]	[-75,546, -68,567]	[-20,973, -18,425]
Net Change in 2090	603	88.6	587.0	-0.69	572	-74,885	123
	[402, 796]	[-136, 306]	[469, 704]	[-1.99, 0.50]	[139, 974]	[-95,898, -53,344]	[-7082, 7311]
Net Present Cost ($2015 Million)	$511.49	$75.8	$502.0	$121.6	-$179.0	$-74.8	$1.64
	[$344, $681]	[$-117, $264]	[$401, $602]	[$306, -$49]	[$-44, $-305]	[$-95.8, $-53.3]	[$-94.3, $97.3]

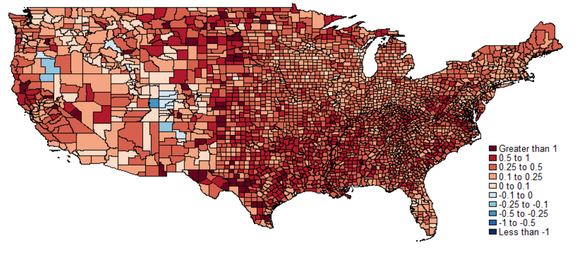
Panel B. 2000-2090 Changes, Quantile Based Correction Method

	Fatalities						
	Full Sample	LDV	ULD	LDV Trips (in billions)	ULD Trips (in billions)	Accidents	Injuries
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sum of Net Changes 2000-2099	27,493	2,927	29,375	-30.0	30.6	-4,396,693	-200,734
	[17,964, 37,179]	[-8,084, 14,524]	[23,625, 35,512]	[-93.0, 29.5]	[9.5, 50.6]	[-5,430,697, -3,332,336]	[-570,886, 160,744]
Sum of Costs ($2015 Million)	$62,603	$4,894.8	$72,991.1	$14,580	-$27,689.96	-$14,639.23	-$16,029.17
	[$38,688, $86,883]	[$-23,157, $34,791]	[$57,702, $89,380]	[$39,248, -$8,605]	[-$10,337, -$44,494]	[$-17,692, $-11,487]	[$-30,938, $-1,444]

Simulation

- Use Hadley 3 A1B Scenario: daily predicted temperature and precipitation
- 4º C of warming, northern regions see change of snowfall to rainfall.
- Use a new Quantile mapping method for correcting weather. Initial Hadley distribution has discrepancies
  - Match full initial distribution while allowing for changes in distribution due to climate change
- From 2015 to 2099 cost of fatalities $63 billion, about half is offset by ULD travel benefits $27 billion
- Possible defensive expenditures for LDV travel. Smaller welfare improvement from accidents and injuries.

Annual Change in Fatalities by 2090



Annual Change in Property Damage Only Accidents by 2090