Does Winter Weather Decrease Work?

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Abstract: It is widely understood that weather affects hours worked, but evidence is rather limited. This paper examines how hours worked among those surveyed in the Current Population Survey (CPS) monthly reference week vary with respect to snowfall in 265 metropolitan areas over the years 2004-2014. Working hours are significantly affected by snow events, with magnitudes varying among types of workers, types of employment (class of worker, occupation, and industry), and region. Overall, each average daily inch of snowfall during a CPS monthly reference week reduces work by about 1 hour. Reductions in hours worked due to each inch of snow are particularly large among construction workers and in the south. We find little evidence that hours lost from large snowfalls are "made-up" in subsequent weeks. A "back-of-an-envelope" calculation suggests that in an average year, snow leads to a 0.15 percent loss in annual hours worked, a small but nontrivial impact. That said, major winter storms can produce substantive month-to-month and regional differences in output growth.

JEL codes: J22 (Time Allocation and Labor Supply); O4 (Economic Growth and Aggregate Productivity); Q54 (Climate)

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I. Introduction

It is commonly argued that bad weather decreases economic activity. This relationship has drawn attention from the Federal Reserve Board, among others. For example, in February 2014 the mass media (e.g., Applebaum 2014; Jeffrey 2014) reported a speech by Janet Yellen, Chair of the Board of Governors of the Federal Reserve System, who blamed the absence of economic growth at the beginning of 2014 in part on the weather.

> *"… A number of data releases have pointed to softer spending than many analysts had expected. Part of that softness may reflect adverse weather conditions, but at this point, it's difficult to discern exactly how much."*

Two months later, Yellen gave another speech at the Economic Club of New York when she talked about "Monetary Policy and the Economic Recovery." She said

> *"The Federal Open Market Committee's (FOMC) current outlook for continued, moderate growth is little changed from last fall. … The unusually harsh winter weather in much of the nation has complicated this judgment, but my FOMC colleagues and I generally believe that a significant part of the recent softness was weather related." (Yellen, Board of Governors of the Federal Reserve System, 2014).*

Consistent with this theme is the experience of Atlanta, GA during its "snowmaggedon" ice storm in January 2014. Just over two inches of snow and ice paralyzed one of the largest metro areas in the country. "Thousands of drivers were hopelessly stuck for a second day, many without food and water, on paralyzed interstates around Atlanta after a winter storm appeared to take the city by surprise."[1] It was nearly impossible to travel on the roads the following two days. The movement of 6 million plus people was squelched by a seemingly minor weather event.

In this paper, we examine the relationship between weekly hours worked and weather, with a focus on snowfall accumulation. Researchers in multiple disciplines have examined the relationship between weather and outcomes such as income, productivity, time-use, health, etc. The economics literature, however, includes few studies on how weather affects labor working hours. To the best of our knowledge, the Current Population Survey (CPS) monthly employment files have not been utilized to examine the relationship between local area working hours and weather during the monthly CPS survey reference week. This is surprising given that the CPS contains large, nationally representative samples of worker reaching back many year in time.

[1] Last retrieve was on April 23, 2017. https://usnews.newsvine.com/_news/2014/01/29/22492664-thousands-still-stranded-on-atlanta-highways-after-snow-catches-south-unprepared

As expected, we find that snowfall during a CPS reference week reduces work hours during that week. The losses in hours worked rise systematically with snow accumulation levels. The relationship between work hours and snow severity differs systematically across types of employment, industry, occupation, regions, and, to a lesser extent with respect to worker or household demographics.

The paper is organized as follows. Section 2 describes literature related to how weather affects labor related outcomes. Section 3 presents a brief discussion of labor supply theory and methods. Section 4 presents information on the data sources, including data on climatology, labor inputs, and other relevant measures. Section 5 presents descriptive data evidence on work hours and snow, and section 6 presents the results, followed by discussion. Section 7 concludes.

II. How Weather Affects Work Hours

Temperature plays a role in determining workers' incomes, although individuals and societies adapt to environmental conditions in ways that mitigate the sensitivity of income with respect to weather variation. Deryugina and Hsiang (2014) find that over a 40 year period, worker productivity decreases with temperature, particularly so for weekdays over 30°C (86°F). These effects changed little over this period (since 1969). There is rather limited empirical evidence, however, on the relationship between weather conditions and work hours. Severe weather events affect short-run labor supply due to direct effects on worker transportation and mobility, or through indirect effects such as a parent staying home with a child due to a school closure. Weather affects consumer activity and the demand for goods and services, which in turn affects labor demand, albeit differently depending on the nature of the work and the demand sensitivity. Weather can also affect work hours indirectly by changing the relative valuation and costs of alternative uses of time (Connolly 2008; Krüger Neugart 2018). For example, good weather may increase the demand for leisure activities and thus reduce the supply of market work hours, although increasing demand for some leisure-related activities in turn increases demand for work hours among employees in businesses catering to such demand.

A growing body of research applies various methodologies to examine the climate-related impacts of temperature, precipitation, air pollution, and windstorms on economic activity and outcomes. These studies focus on how changes in weather over time in given spatial areas affect outputs of agriculture and industries, labor productivity, time-use, energy demand, health, conflict, and economic growth (Dell, Jones, & Olken, 2014).

Geographer Ellsworth Huntington's (1915) *Civilization and Climate* provided early evidence showing the relationship between temperature and productivity. Huntington finds that productivity was highest in spring and fall when temperatures are moderate, while lowest in summer and winter when temperatures are more extreme. Connolly (2008) examines the impact of rainfall on the labor/leisure choice in the U.S. using the American Time Use Surveys (ATUS). She finds that men substitute about thirty minutes per day, on average, from leisure to work on rainy days. Lee, Gino, and Staats (2014) show that good weather creates distractions that decrease productivity among Japanese bank workers; individuals appear to focus less on work when there are attractive alternate activities. Krüger Neugart (2018) use German time use data from 2001-2002 linked to weather data. Their study is unique in that it has multiple diary days for individuals, allowing them to use worker fixed effects and measure how day-to-day work hours vary with weather for given workers. Substitution between leisure and work is highest among workers who have jobs with flexible work hours. The authors find modest interday variation in hours among women but not among men, the opposite of Connolly (2008).

Zivin and Neidell (2014) use the individual-level data from the 2003–2006 ATUS linked to weather data from the National Climatic Data Center. They show that fluctuations in temperatures lead to substantive changes in labor supply. They find reductions in work hours in climate-exposed industries such as agriculture, forestry, mining, construction, and utilities, when temperature exceed 85˚F. Responses were particularly large at very high temperatures. For example, daily work hours in climate-exposed industries decline by as much as one hour at temperatures over 100˚F, as compared to the 76-80˚F range. Ziven and Neidell find little evidence of interday substitution of hours in the workplace.

In contrast to the prior studies focusing on rain and temperatures, we are unaware of prior analyses of snow events. Snow events are less frequent than are rain and extreme temperatures, but potentially have large labor supply effects concentrated in time and place. An interesting paper related to our analysis is Boldin and Wright (2015). Whereas we examine how weather affects work hours using worker-specific household data (the CPS), Boldin and Wright examine the relationship between weather and employment/hours fluctuations in the Current Employment Statistics (CES) establishment surveys from BLS, which are used along with the CPS in the Bureau of Labor Statistics (BLS) monthly employment reports. Boldin and Wright explore how one might construct new "seasonally adjustment" methods that incorporate current monthly weather data. Standard seasonal adjustment methods used in the BLS monthly employment reports account for historical fluctuations in monthly employment, but this does not adjust for the current month's weather. Boldin and Wright show that it may be feasible to use current month/year-specific seasonal adjustments.

III. Methods

The study of labor supply has a long history in the economics literature; for background, see Pencavel (1986). Hours within a week (or other period) is divided into time devoted to market work, home production, and leisure. Labor supply involves individual or joint decisions made by persons within households over time. Optimal supply decisions are based on wage opportunities, non-earnings income, and the alternative valuations (preferences) with respect to money income, leisure, and home production activities. Changes in wage opportunities have substitution and income effects of opposite sign. In practice, work hour outcomes are determined by demand-side (employer) as well as supply-side forces.

Given the difficulty of estimating structural labor supply models, we simply estimate reduced-form measures of labor supply (weekly hours of work) as a function of labor supply and demand determinants, excluding an hourly wage measure on the right-hand side.[2] To understand the impact of weather (snow events) on hours worked, we estimate the following relationship:

$$h = f(Climate, X)$$

Here *h* is a measure of hours worked, *X* is a vector of variables affecting labor supply and/or demand other than climate effects, and *Climate* can include temperature, precipitation, and weather events. Our focus is on snowfall accumulation, as described subsequently. Using standard methodology, the general regression form used in this paper is as follows:

$$h_{ijt} = \alpha + \beta Climate_{ijt} + \gamma X_{ijt} + \varepsilon_{ijt}$$

where *h*, *Climate*, and *X* are as stated above, i indexes individual workers, *j* indexes the metro area CBSAs, and *t* indexes time (the survey reference week is the second week of each

[2] In order to use all CPS rotation groups rather than just the quarter samples (i.e., the outgoing rotation groups) that report earnings, we exclude a wage variable. Moreover, because CPS hourly earnings are typically calculated as weekly (or annual) earnings divided by hours worked, a labor supply equation with hours (*h*) on the left-hand side and the implicit wage (*E/h*) on the right-hand side, there is a "division bias" in which measurement error in *h* that mechanically drives the wage coefficient (i.e., the labor supply elasticity estimate) toward negative one in a double logarithmic specification (Borjas, 1980). Given that such labor supply elasticities are close to zero, we should not expect exclusion of the wage to create substantive bias in measuring the effect of snowfall on hours worked. We confirm that snowfall coefficients are highly similar using the ORG quarter sample with a wage variable included.

month/year)[3], and ε is the error term. As explained subsequently, we estimate the hours worked equations in linear and semilogarithmic form and use alternative measures of hours worked.

Unlike most other determinants of hours worked, the timing of local area weather events such as snow plausibly vary independently of the other determinants of work hours. In short, weather shock events provide strong identification properties (Dell, Jones, & Olken, 2014).

IV. Data Description

Four major types of weather data are currently used for econometric analyses in empirical studies: ground station, gridded, satellite, and reanalysis data. The most basic and frequently used weather data are from ground stations, which typically record directly the air temperature, precipitation, and snowfall, as well as other measures such as sky cover, sunshine, humidity, water, and wind related information. Gridded data provide more complete coverage by calculating micro-area weather conditions based on interpolation of information from multiple stations over a wide grid. Satellite data use satellite-based readings to infer various weather variables. Finally, reanalysis data combine information from ground stations, satellites, weather balloons, and other sources, using climate models to estimate weather variables across a grid. Our study uses ground station data, as described below.

IV-A. Climatological Data

Our weather data are from the National Oceanic and Atmospheric Administration (NOAA). NOAA's work dates back to 1807, providing comprehensive data from "the surface of the sun to the depths of the ocean floor." The National Centers for Environmental Information (NCEI) have integrated three data centers (The National Climatic Data Center, The National Geophysical Data Center, and the National Oceanographic Data Center), which provide comprehensive historical data on ocean, atmosphere and geography. We use one of the NCEI datasets from the National Climatic Data Center, the Global Historical Climatological Network-Daily (GHCN-Daily) (Menne, Durre, Vose, Gleason, & Houston, 2012). The GHCN-Daily dataset integrates daily climate observations from approximately 30 different data sources. Version 3, initially released in September 2012, provides 7 days a week data rather than only

[3] The definition of "second week of each month" in the CPS is the week that includes the 12th of the month. In some specifications, we include snow events in weeks prior to the reference week.

weekdays. Meteorological elements used in this research are snowfall and weather type from the years 2004 through 2014.[4] The GHCN-Daily, however, is not limited to those variables.

The unit of analysis we choose are metropolitan areas, as delineated by the Census Bureau as Core Business Statistical Areas (CBSAs). Most CBSAs are identified in the Current Population Survey (CPS), the exception being small CBSAs, typically with populations below 100,000. The available analysis units in GHCN-Daily include countries, states, counties, cities, and zip codes to climate divisions and climate regions, as well as hydrologic units.

In order to match CPS metropolitan areas (CBSAs) with appropriate weather data, we have taken several steps. The first step was identifying the counties that are included in each CBSA. We used the historical delineation file, "Counties with metropolitan and micropolitan statistical area codes," released on June 6, 2003 by the U.S. Census Bureau (2003). There are 370 CBSAs in 50 states (plus the District of Columbia and Puerto Rico) with 1158 counties in the file. However, the CPS does not identify all CBSAs and does not include Puerto Rico.[5] These CBSAs codes were adopted by the CPS beginning in May 2004 and were continued through 2014.[6] As previously stated, the CPS excludes the smallest CBSAs, roughly those with populations below about 100,000. In the CPS, there are a total of 265 CBSAs in 50 states and the District of Columbia, which include 908 counties. Approximately three-quarters of the U.S. population is represented in the CPS metro (CBSA) sample.

Our second step was to identify the most highly-populated county in each CBSA. There are 103 CBSAs that include only one county and 162 CBSAs with two or more counties. For the latter group, it is reasonable to assume that weather recorded from stations within the most-populated county should have the most substantial economic influences. Moreover, most weather conditions are similar across contiguous counties within the same CBSA. This would generally

[4] There are a total of 12 different weather types; for details see Appendix 1. The weather types we define as a "Snow event" in this paper are wt04 which is "Ice pellets, sleet, snow pellets, or small hail", wt09 which is "Blowing or drifting snow", and wt18 which is "Snow, snow pellets, snow grains, or ice crystals". In some of our analyses, we use this comprehensive (albeit categorical) measure of a "snow event" based on there being one or more of these relatively infrequent but sometimes severe events that may not produce substantive accumulations on the ground. Most of our analyses use a simple continuous measure of average daily snow accumulations (in inches) over the 7-day CPS reference week, as described below.

[5] Workers not in a designated MSA are in either a small MSA with populations in the 50 to 100K range or are in a non-metro area of the state.

[6] In mid-year 2014, the CPS made changes with some code number changes and some small MSAs being added. 17 CBSAs' codes adopted mid-year in 2014 were converted to the time consistent earlier codes.

be the case for such conditions as snow, rain, and temperatures, although far less so for tornadoes or other weather conditions with highly-localized coverage.

Our third step was calculating the snowfall information from the GHCN-Daily database. Each county contains multiple stations, with the number of stations within counties varying from 1 to 472 (252 counties contain less than 100 stations). For each county matched to a CBSA we obtain the daily information on snowfall and weather type.[7] The unit of snowfall is inches. Daily snowfall is summed across all stations within a county; our measure of daily snowfall is the average inches across the within-county stations (all stations receive equal weight). For our primary analysis, we calculate the average daily inches of snow across the 7 days in each CPS reference week.

The CPS household employment survey, conducted in the third week of the month, obtains labor information on employment status and hours worked for the previous (second) week of the month (i.e., referred to as the reference week). Hence, our snowfall measure represents the average daily snowfall during the CPS reference week. An alternative "snow event" categorical value is coded as 1 if one or more weather stations within a CBSA record one of the three events described previously (footnote 4) during the CPS reference week.

IV-B. Labor Data

As a measure of work hours, the Current Population Survey (CPS) provides information on usual hours worked per week in one's primary job, usual hours in a second job if a multiple job holder, and measures of actual hours worked the previous week in the primary job and hours last week in all other jobs. The three measures of hours used in this analysis are (a) hours worked last week on all jobs; (b) usual hours worked per week in one's primary job and a second job (about 5 percent of worker are multiple job holders); and (c) the difference between (a) and (b).

Given the rich set of individual worker controls in the CPS, we can examine how the response to weather varies by type of job (hourly, salaried, or self-employed), occupation, industry, and demographics. The hours worked questions are asked of all CPS rotation groups and not just the quarter sample (the outgoing rotation groups) that are asked questions on earnings and unionization. This also means that we typically observe the same individual in four consecutive months and for two adjacent years for those same four months (assuming the

[7] All snowfall data values reported provide a quality measurement flag. We exclude snow values designated as having a quality assurance issue (this is a tiny proportion of values, about 0.5% of total observations).

household residence remains the same). We do not use the quasi-longitudinal structure of the data (i.e. within-worker monthly differences in hours in response to differences in snowfall).

A downside of using CPS work hours data, as opposed to time diary measures of work, is that worker responses are "heaped" at common work hours. Hirsch (2005), in an analysis of part-time work, examines the frequency distributions of usual hours worked per week (on the principal job) and mean wages by hours worked. He used full CPS-ORG earnings files for September 1995-2002. He finds that 53% of women and 57% of men reported their usual hours worked per week as 40. As compared to men, the hours distribution among women contains more low-hour and fewer high-hour observations, and is more dispersed. There exist "spikes" or "heaping" at intervals divisible by five, a common survey phenomenon, and an appreciable numbers of workers at hour intervals divisible by 8, in particular, 24, 32, and 48, in addition to 40. The distribution of "hours worked last week" is more dispersed, with fewer workers reporting exactly 40 hours: 42% among women, 45% among men. Most of our analysis examines hours worked last week (i.e., the reference week). We also examine a measure of deviations from usual hours; that is, the hours worked last week minus usual weekly hours.

To avoid high influence observations, we omit the very tiny proportion of individuals reporting more than 90 hours (the hours variables are topcoded at 99 hours). Excluded from analyses using usual weekly hours are those who report usual hours that are "variable" (coded as "-4" by Census). These workers are excluded from analyses using usual weekly hours; most analyses use hours worked last week.

Some employed workers may not have worked during the reference week due to being on vacation, ill, weather, etc. For the measure of hours worked last week, the CPS asks employed workers who report zero hours the reason for their not being at work. There are eight reasons for participants to choose from in the survey.[8] Absent weather data, one could examine the frequency of not at work last week due to bad weather. That number, however, is tiny even in high-snow states since it is rare to miss an entire week due to weather.[9] We remove workers who state zero hours last week for any reasons other than bad weather.

[8] The 8 reasons in the survey for absence from work are. 1. Own illness; 2. On vacation; 3. Bad weather; 4. Labor dispute; 5. New job to begin within 30 days; 6. Temporary layoff; 7. Indefinite layoff; 8. Other.

[9] There are 4,780 observations in our CPS sample reporting zero hours last week due to bad weather.

The CPS also includes numerous other demographic, geographic, and labor market variables. We construct variables measuring such things as age, race, ethnicity, gender, educational level, potential experience, and sets of dummies measuring month, CBSA size, region, occupation, and industry.

In our merged CPS-weather dataset, we measure snow in the reference week (the second week of each month), as well as weeks one, two, and three weeks prior to the reference week. Information on prior weather allows us to examine whether there is a "make-up" effect that partially offsets hours lost during prior snow event. That is, we ask whether we see higher (or lower) work hours in the reference week when there has been snow in previous weeks.

V. Descriptive Evidence on Work Hours and Weather

Figure 1, seen below, shows the average hours worked last week by major Census region by month, averaged over the 2004-2014 period. The mean hours worked during the reference week differs across regions, but these differences are relatively stable between May and August. Mean hours are typically lower between October and March, the months over which most snow accumulations occur. On average, the highest hours worked is in the West South Central region

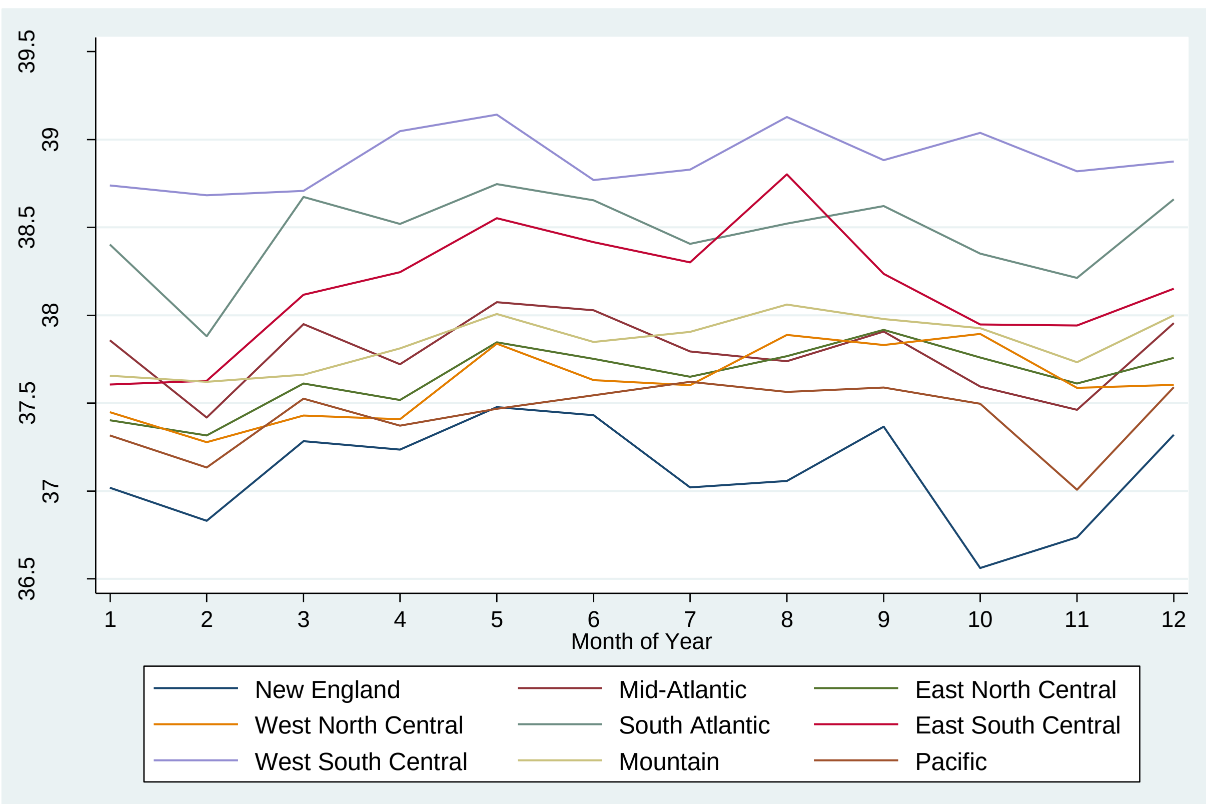

Figure 1: Total hours worked last week by region by month, USA 2004-2014

and lowest hours worked is in New England. These patterns are consistent with there being snow effects on work hours. Our subsequent analysis examines the direct relationship between local snow accumulation and individuals' work hours in the week prior to the monthly CPS surveys.

Table 1 provides basic information on the hours worked last week measure in our estimation sample. For the overall sample, there are roughly 5.8 million observations of employed workers reporting hours worked in the reference week period (i.e., the second week of each month, prior to conduct of the CPS survey). The mean of hours worked is 37.9 hours per week, about two hours less than typical modal value of 40 hours per week among full-time workers (part-time workers pull down mean hours). We also consider the mean value of hours worked last week in two subsamples, one for periods without snow and the other with snow. There are small but substantive differences between the two sample periods, with an average 22 minutes less work during weeks with snow. We conduct a two-sample t test with equal variances; the mean difference is statistically significant with a t-value of 28.53.

Table 1: Summary of hours worked last week

	Total Observations	Mean	Std. Dev.	Min	Max
	All data				
hours worked last week	5,765,988	37.89	12.68	0	99
	Data conditional on snow				
hours worked last week	1,270,219	37.60	12.81	0	99
	Data conditional no snow or missing				
hours worked last week	4,495,769	37.97	12.64	0	99

Returning to the weather data, Figure 2 demonstrates the average snowfall for 9 different regions in each month through 2004 to 2014, respectively. The pattern of snow is consistent with the information seen previously in Figure 1. Most regions receive the most snow in first three and last three month of the year (i.e., between October and March). In much of the subsequent analysis, we restrict our analysis to these six months. Consistent with the concentration of snow events in these months, we see slightly higher variation of weekly work hours within regions during these six months. This result can be confirmed in the Table 2 by the differences in the coefficient of variation across regions. The first two columns of Table 2 show the number of observations and coefficients of variation over April to September each year by regions, whereas the last two columns indicate October to March in the following year.

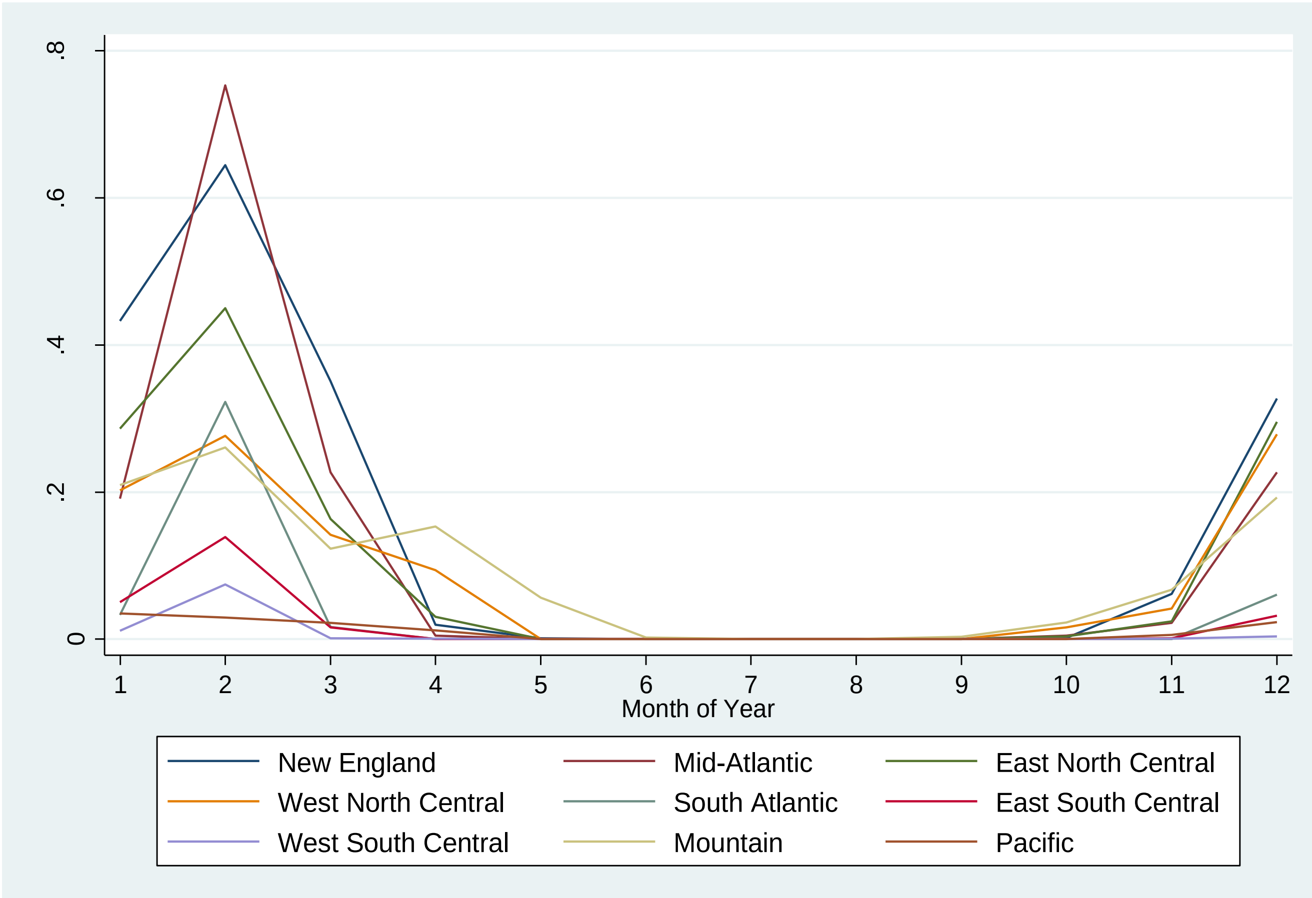

Figure 2: The average snowfall by region by month, USA 2004-2014

Consistent with the concentration of snow events in these months, we see slightly higher variation of weekly work hours within regions during these six months. This result can be confirmed in the Table 2 by the differences in the coefficient of variation across regions. The first two columns of Table 2 show the number of observations and coefficients of variation over April to September each year by regions, whereas the last two columns indicate October to March in the following year.

As seen in Figure 2, among the 9 regions, New England received the most snow in the winter period, followed by East North Central and West North Central. The Pacific, East South Central, and West South Central regions receive minimal snow. The other three regions typically have snow events during a year, but the number is small. The evidence on work hours and snow levels for regions by month, as seen in Figures 1 and 2, clearly suggest a possible link between hours worked and snow events.

Table 2: The standard deviation of hours worked by region

	Hours worked April-September		Hours worked October-March	
	(1) Observations	(2) Coefficient of variation	(3) Observations	(4) Coefficient of variation
Northeast	292,809	35.62	289,319	36.09
Mid-Atlantic	333,749	32.60	324,975	33.04
East North Central	364,204	34.24	353,529	34.62
West North Central	255,066	34.88	250,302	35.01
South Atlantic	575,364	31.10	564,390	31.63
East South Central	104,225	32.42	101,000	33.11
West South Central	255,964	31.96	251,835	32.14
Mountain	264,373	33.64	260,174	34.00
Pacific	456,489	33.80	448,802	34.33

VI. Empirical Results

Table 3 shows our base relationships between three alternative work hour measures and the inches of snowfall in the reference week for 265 CBSAs over the 2004 to 2014 period. Each of the regressions has a rich set of covariates, listed in the table note (snowfall coefficients absent covariates tend to be slightly larger in absolute value). Column (1) has as its dependent variables the hours worked last week; column (2) the log of hours worked last week (observations with zero hours drop out); and column (3) measures the difference between hours last week and usual hours per week.

Focusing first on column (1), we find that an inch of average daily snowfall over a week decreases work hours by just under an hour (0.9 hours or 54 minutes). In column (2), use of the log of hours last week indicates a 3 percent decrease in hours worked (1.1 hours or 68 minutes), a somewhat larger estimate as compared to column (1). Column (3) provides a rather different dependent variable, measuring the difference between "actual" hours worked in the reference week minus "usual" weekly hours (those with "variable" usual hours are omitted). In principle, this is an attractive measure, reflecting how snow during the week alters person-specific hours of work. Here we obtain a coefficient indicating each inch of average daily snow is associated with 0.64 fewer weekly hours (38 minutes) than usual, less than the 0.90 hour effect we saw in column (1).

Table 3: The relationship between hours worked last week and snowfall in the reference week

	(1) Hours worked last week	(2) Log hours worked last week	(3) Hours worked difference
Inches snow	-0.897***	-0.0305***	-0.635***
	(0.200)	(0.00671)	(0.154)
Observations	2,490,454	2,486,595	2,487,691
R-squared	0.152	0.124	0.006

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Note: There are 3 hours worked regressions with alternative dependent variables. The table presents the estimated coefficient (and standard error) on the snow variables. All robust standard errors (in parentheses) are clustered at the CBSA level. Each regression controls demographic information on age, race, sex, educational level, experiences, plus sets of dummies for Month, CBSA size, Region, Broad Occupation, and Broad Industry.

Note that interpretation of results is a bit tricky given that our main snow measure represents the daily inches of snow averaged over the entire week. That is, there is no distinction made between there being one inch of snow each day of the week versus there being one day of snow with 7 inches. In future research, we plan to investigate how worker response differs depending on how levels of snow are distributed over a week.

In Table 4, we examine whether work hours are affected by snow in previous weeks, all else the same. Of particular interest is whether the loss of hours worked in prior weeks due to snow leads to “make-up” hours in subsequent weeks. In panel A, we consider the effect of snow occurring one week prior to the reference week, conditional on no subsequent snow in the reference week. In Panels B and C, we consider the effect of snow two weeks and three weeks prior to the reference week, respectively, conditional again on no snow in subsequent weeks. Columns (1) includes the full winter sample, as used previously. Given that spillover or make-up work effects should only be evident for severe snow events, in column (2) we restrict the sample to weekly snow amounts average 2 inches daily or more, reducing the sample included from 1.24 million worker observations in column (1) to just under 16 thousand observations in column (2).

Our initial focus is on column (1), which includes the full winter sample for which most snow events are unlikely to have work hour spillover effects in subsequent weeks. Not surprisingly, coefficients in column (1) are tiny and in most cases insignificant. The -0.27 coefficient in panel B is statistically significant, but trivial in size, implying that each average daily inch of snow from two weeks prior reduces current work hours by about 16 weekly minutes. Results in column (2), which is limited to major weekly snow events, are intriguing. For major snow events in the prior week (panel A), the -0.67 coefficient implies a negative spillover or

Table 4: The relationship between hours worked last week and past snowfall

	(1) Hours worked last week Full winter sample	(2) hours worked last week Winter sample with 2” or more snow
A. Snow is one week before the reference week		
Snow	-0.128	-0.674**
	(0.0922)	(0.313)
Observations	1,687,925	19,821
R-squared	0.146	0.217
B. Snow is two weeks before the reference week		
Snow	-0.272**	0.424**
	(0.107)	(0.169)
Observations	1,396,900	12,663
R-squared	0.144	0.183
C. Snow is three weeks before the reference week		
Snow	-0.167	0.0850
	(0.159)	(0.0570)
Observations	1,239,392	15,808
R-squared	0.142	0.196

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Note: This table presents the estimated coefficient (and standard error), all robust standard errors are clustered at CBSA level in the parenthesis. Each panel show the snow in the different weeks prior the reference week. There is no snowfall in between current week and reference week, in other words, when we look at the prior week, we exclude the observation with any snow in the following week. There are total 6 regressions, and each regression controlled demographic information such as age, race, sex, educational level, experiences as well as five sets of dummies. Month dummies with October omitted, CBSAs size dummies with size 2 omitted; region dummies with

New England omitted; occupation dummies with "Management, Business, Financial" omitted; and industry dummies with "Agriculture, Forestry, Fishing, and Hunting" omitted.

residual effect in the subsequent CPS reference week of 40 minutes less work. For example, snowfall occurring on a Saturday is likely to negatively affect hours worked the following week.

For major snow events two weeks prior (panel B), we obtain a positive coefficient of 0.42, implying that a major storm two weeks prior results in a hint of "makeup" work of 25 minutes for each inch of average daily snow two weeks earlier. The estimates with different signs for panels A and B each seem plausible (negative residual effects in A and makeup work in B), but we are reluctant to generalize or place substantial weight on these (interesting) results. Both spillover and makeup work hour effects are plausible; our empirical analysis is not sufficiently powerful to precisely identify such effects.

In analysis not shown, we estimated similar models separately by industry. For a few industries, we found positive (but small) coefficients on previous week snowfall, suggestive of tiny work hour make-up across weeks. In our subsequent analyses, we will focus exclusively on snow events during the reference week.

In results presented up to this point, we have measured snowfall in inches, assuming (implicitly) an approximately linear relationship between work hours and average daily inches of snowfall. Alternatively, we estimate hours worked equations using a set of 5 categorical snowfall level dummies to better understand how levels of snowfall affect work hours.

Table 5 shows the results of the relationship between hours worked last week and five categorical snow-level dummies. The omitted category is no "snow event" during the week, based on the three events stated previously in footnote 4. Our included snow-level dummies include increasing ranges of average daily inches. The lowest snow level measure ranges from average daily inches levels of zero to 0.1 inch (many "snow events" produce zero snow accumulation). The additional dummies reflect average daily inch ranges of 0.1-0.5, 0.5-1.0, 1.0-2.0, and 2.0 or more inches. We consider the snow below 1 inch as "light" snow, more than 2 inches as "heavy" snow, and in between as "moderate" snow.

As expected, higher levels of snow result in larger reductions in hours worked during the reference week, as shown in Table 5. Snow level coefficients range from -0.203 (12 minutes less work in the reference week) for average daily snow of zero to 0.1 inches (many of these are snow events with no accumulation) to a substantial 3.0 fewer hours in the reference week for average daily snow exceeding 2 inches. Similar results are seen in columns (2) and (3) using the alternative semi-log specification (column 2) or the alternative hours measure (column 3). Using the semi-log specification, we obtain an estimated 10 percent hours reduction for average daily snow levels greater than 2 inches. In column 3, our estimate is that average snow levels over 2 inches result in 2.3 fewer hours worked in the reference week as compared to usual weekly hours. The overall range of coefficients is from 0.07 hours (5.4 minutes) for snow with minimal accumulation up to 2.3 hours for the most substantive accumulations. Notable in all three of the specifications are the large increases (in absolute value) of the coefficients once average snow levels exceed the 2-inch threshold. Although such heavy snow events are rare, the magnitude of work loss resulting from such events are substantial, consistent with the emphasis given to unusual weather by Janet Yellen and the Federal Reserve Board.

Table 5: The relationship between hours worked last week and snow level

	(1) Hours worked last week	(2) Log hours worked last week	(3) Hours worked difference
Snow greater than 0 - 0.1’’	-0.203***	-0.00580***	-0.0692***
	(0.0537)	(0.00210)	(0.0207)
Snow b/w 0.1’’-0.5’’	-0.409***	-0.0129***	-0.161***
	(0.0639)	(0.00234)	(0.0379)
Snow b/w 0.5’’-1’’	-0.760***	-0.0256***	-0.364***
	(0.130)	(0.00449)	(0.0783)
Snow b/w 1’’-2’’	-0.879***	-0.0287***	-0.518***
	(0.137)	(0.00461)	(0.116)
Snow greater than 2’’	-3.043***	-0.102***	-2.320***
	(1.125)	(0.0378)	(0.810)
Observations	2,490,454	2,486,595	2,487,691
R-squared	0.152	0.124	0.006

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Note: This table presents the estimated coefficient (and standard error). All robust standard errors are clustered at CBSA level in the parenthesis. There are total 3 regressions, and each regression controlled demographic information such as age, race, sex, educational level, experiences as well as five sets of dummies. Month dummies with October omitted, CBSAs size dummies with size 2 omitted; region dummies with New England omitted; occupation dummies with “Management, Business, Financial” omitted; and industry dummies with “Agriculture, Forestry, Fishing, and Hunting” omitted.

In the tables that follow, we examine how the relationship between work hours and snow events differ across types of workers and types of jobs. There may be different incentives to vary work hours in response to snow for salaried versus hourly workers. One possibility is that salaried workers reduce hours more so than hourly workers since their weekly earnings do not directly vary with hours worked. In addition, salaried workers may have greater flexibility to work from home during weather events. On the other hand, hourly workers may be more affected by reductions in labor demand during snow events due to reduced consumer activity when travel is difficult. For example, hourly workers in retail and food stores may have their hours reduced due to lack of demand following snow events. That said, if schools are closed and many adults are home from work, there could be increased demand at restaurants, movie theaters, and the like if travel is possible.

Table 6 provides evidence on hourly and salaried workers' response to snow events. We used two alternative samples. Using the full sample (columns 1 and 2), coefficients on inches of daily snow reflect both the response from going from zero to positive snow levels plus the marginal effects of additional snow. Inclusion only of those observations in which there has been a snow event sharply reduces the size of the zero-based reference group, previously dominated by observations in which there is no snow event. Using the snow event sample (columns 3 and 4), the zero base group reflects snow events in which there has been no accumulation of snow. As expected, coefficients are somewhat smaller (in absolute value) excluding observations without a snow event.

Table 6: Snowfall effects on hours worked for salaried versus hourly workers

	(1) Salaried	(2) Hourly	(3) Salaried	(4) Hourly
	Full sample		Snow event sample	
Snow	-0.987*** (0.245)	-0.800*** (0.186)	-0.830*** (0.114)	-0.597*** (0.145)
Observations	248,566	325,783	65,665	91,936
R-squared	0.087	0.185	0.093	0.200
Difference		-0.187*		-0.233*
Chow- Test	Chi (2) = 2.88 Prob > Chi2 =0.0897		Chi (2) = 3.15 Prob > Chi2 =0.0760	

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Note: This table presents the estimated coefficient (and standard error), all robust standard errors are clustered at CBSA level in the parenthesis. There are total 4 regressions, and each regression controlled demographic information such as age, race, sex, educational level, experiences as well as five sets of dummies. Month dummies with October omitted, CBSAs size dummies with size 2 omitted; region dummies with New England omitted; occupation dummies with "Management, Business, Financial" omitted; and industry dummies with "Agriculture, Forestry, Fishing, and Hunting" omitted.

As previously predicted, salaried workers display stronger work hours sensitivity and/or flexibility with respect to snowfall accumulation in both samples. The differences in responses for salaried and hourly workers are relatively small, but consistent across the two samples (0.187 in the full sample and 0.233 in the snow event sample). We conducted a Chow test to examine the significance of coefficient differences between the salaried and hourly workers. In both the full and snow event samples, Chow tests indicate that the coefficient differences are significant at the 10% level.

We next examine differences among wage and salary workers whose primary jobs are wage and salaried in the private sector, wage and salaried in the public sector, and self-employed. Public sector workers are likely to be most affected by the snow given large number of public employees in education. Public schools place a high weight on students' safety; hence, when weather makes travel dangerous, classes are canceled or delayed. In contrast, workers self-employed and in the for-profit private sector are typically less affected (on average) by snow events. Self-employed workers earnings may be particularly sensitive to hours worked, making it costly to reduce work in response to the weather. Moreover, many workers who are self-employed work out of their home and may be largely unaffected by weather conditions.

Table 7 shows the relationship between hours worked last week and snowfall for the public, private, and self-employed workers. Columns 1-3 report results for these three sectors using the full winter sample, while columns 4-6 restrict the sample to snow event weeks. The

Table 7: The relationship between hours worked last week and snowfall conditional on different employment type

	(1) Public	(2) Private	(3) Self-Employed	(4) Public	(5) Private	(6) Self-Employ
		Full sample			Snow event sample	
Snow	-1.56***	-0.780***	-0.694***	-1.08***	-0.630***	-0.491***
	(0.380)	(0.164)	(0.189)	(0.194)	(0.118)	(0.177)
Observations	373,464	1,892,618	224,372	94,728	527,375	61,605
R-squared	0.100	0.184	0.110	0.120	0.199	0.110

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Note: The table presents the estimated coefficient (and standard error), robust standard errors are clustered at CBSA level. There are total 6 regressions, and each regression controlled demographic information such as age, race, sex, educational level, experiences as well as five sets of dummies. Month dummies with October omitted, CBSAs size dummies with size 2 omitted; region dummies with New England omitted; occupation dummies with "Management, Business, Financial" omitted; and industry dummies with "Agriculture, Forestry, Fishing, and Hunting" omitted.

qualitative results are consistent with our expectations. Public sector workers display a negative hours response to snow twice as large as that seen for the private and self-employed sectors. Although coefficients are smaller in the snow event only sample, they remain much larger (in absolute value) for public than for private wage and salary and self-employed workers.

Next, we examine the heterogeneity of snow effects on work hours across different industries and occupations. The sample examining differences in snow effects by industry group include only private sector workers, given that the public sector was examined above. The sample examining snow effects by occupational groups includes all sectors, since we see workers in many occupations employed in both the public and private sectors.

Tables 8 and 9 show the relationship between snowfall and hours worked last week in different industries and occupations, respectively. Each column in the two tables indicates a specific industry or occupation group. The two panels use different data samples: panel A is the full winter sample; panel B is the snow event sample.

In table 8, panels A and B, we find negative work hour effects from snowfall in all industries. Coefficients using the snow-event sample tend to be somewhat smaller (in absolute value) as compared to the full sample, but not in all industries. The largest negative impact of snow on work hours is in the construction industry, where a considerable share of the work is outside. In addition to the construction industry, we find substantial work hour effects from snow events in agriculture, forestry, fishing & hunting, the leisure and hospitality industry, transportation and utilities, and service-related industries (columns 9-12). The least affected industries tend to be indoor-intensive industries such as information and financial activities. In terms of magnitude, coefficients close to -1.0 reflect a one hour weekly reduction in work for each average daily inch of snow. This magnitude may not be perceived as large, but that may be misleading. First, work hours lost on a snow day within a week may be offset by additional hours on other days within that week. Second, many workers routinely report 40 hours of work and/or may not fully report deviations in work hours due to snow (or other) events. Third, our (necessary) analysis linking *weekly* hours worked to weekly snow may lessen precision of the analysis. While we have daily measures of snow, we do not have daily measures of work hours.

Table 9 provides results for the analysis of broad occupational groups. The occupation results echo the results seen for industry groups. Hours worked by those in farming, fishing, and forestry occupations are most affected by snow events (a snow level coefficient of -1.6). Also

Table 8: The relationship between hours worked last week and snowfall in different industry

	(1) Agriculture., Forestry, Fishing, Hunting	(2) Mining	(3) Constr.	(4) Manuf.	(5) Wholesale Retail Trade	(6) Transp., Utility	(7) Infor.	(8) Financial Activities	(9) Prof., Business Service	(10) Educ., Health Service	(11) Leisure, Hosp.	(12) Other Services
A. Snow is in the reference week (all data)												
Snow	-0.996*	-0.478	-1.332***	-0.601***	-0.649***	-0.852***	-0.435**	-0.637***	-0.887***	-0.781***	-0.987***	-0.985***
	(0.572)	(0.629)	(0.235)	(0.106)	(0.144)	(0.153)	(0.197)	(0.132)	(0.280)	(0.172)	(0.202)	(0.347)
Observations	10,975	7,489	119,815	243,874	321,961	87,103	54,565	169,033	235,597	352,599	191,137	98,470
R-squared	0.151	0.103	0.080	0.082	0.239	0.092	0.153	0.106	0.125	0.115	0.294	0.181
B. Snow is in the reference week (snow event)												
Snow	-1.153	-0.695	-1.087***	-0.572***	-0.604***	-0.623***	-0.531***	-0.635***	-0.575***	-0.626***	-0.804***	-0.475**
	(0.760)	(0.700)	(0.209)	(0.121)	(0.139)	(0.211)	(0.203)	(0.132)	(0.144)	(0.159)	(0.173)	(0.219)
Observations	2,265	1,702	29,041	77,556	90,586	23,985	15,297	49,151	61,276	100,383	50,144	25,989
R-squared	0.187	0.120	0.089	0.085	0.255	0.109	0.170	0.118	0.137	0.121	0.304	0.190

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Note: This table presents the estimated coefficient (and standard error), all robust standard errors are clustered at CBSA level in the parenthesis. There are total 24 regressions, and each regression controlled demographic information such as age, race, sex, educational level, experiences as well as four sets of dummies. Month dummies with October omitted, CBSAs size dummies with size 2 omitted; region dummies with New England omitted; and occupation dummies with "Management, Business, Financial" omitted.

Table 9: The relationship between hours worked last week and snowfall in different occupation

	(1) Management, Business Financial	(2) Professional, Related	(3) Services	(4) Sale, Related	(5) Office, Admin Support	(6) Farming, Fishing, Forestry	(7) Construction, Extraction	(8) Installation, Maintenance, Repair	(9) Production	(10) Transportation, Material Moving
A. Snow is in the reference week (all data)										
Snow	-0.847***	-1.081***	-0.745***	-0.814***	-0.898***	-1.562**	-1.086***	-0.588***	-0.650***	-0.859***
	(0.250)	(0.242)	(0.202)	(0.144)	(0.226)	(0.614)	(0.211)	(0.191)	(0.124)	(0.224)
Observations	411,142	634,385	348,176	276,490	342,384	9,371	121,283	82,668	135,301	129,254
R-squared	0.066	0.107	0.188	0.242	0.113	0.148	0.048	0.056	0.073	0.154
B. Snow is in the reference week (snow event)										
Snow	-0.502***	-0.794***	-0.575***	-0.769***	-0.699***	-1.392**	-0.836***	-0.552***	-0.711***	-0.747***
	(0.100)	(0.146)	(0.130)	(0.131)	(0.209)	(0.604)	(0.230)	(0.187)	(0.164)	(0.204)
Observations	112,879	173,826	91,780	76,240	96,272	1,988	30,258	22,374	42,069	36,022
R-squared	0.072	0.118	0.197	0.258	0.125	0.209	0.051	0.060	0.083	0.163

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Note: This table presents the estimated coefficient (and standard error), all robust standard errors are clustered at CBSA level in the parenthesis. There are total 20 regressions, and each regression controlled demographic information such as age, race, sex, educational level, experiences as well as four sets of dummies. Month dummies with October omitted, CBSAs size dummies with size 2 omitted; region dummies with New England omitted; and industry dummies with “Agriculture, Forestry, Fishing, and Hunting” omitted.

showing large hours effects are workers in the following occupation groups: construction (-1.1), professional services (-1.1), office and administrative support (-0.9), transportation and material moving (-0.9), and management, business, and financial (-0.8). Workers in installation, maintenance, and repair occupations had the lowest reduction (-0.6), not surprising given that some of these workers may increase work hours to provide snow-related repairs.

A final analysis explores the relationship between hours worked last week and snowfall separately by region. Table 10 provides these results. Northern regions typically receive the most snow and southern regions the least snow, as seen previously in Figure 10. People in the north have adapted to driving, commuting, and shopping with snow on the ground. Northern municipalities have equipment and personnel to clear snow off streets. And office and retail buildings are constructed to allow workers and shoppers to move around cities protected from the cold. Not surprisingly, people and local governments in the south, where snow is infrequent, are not prepared to handle substantive accumulations of snow or ice. Therefore, cities in south may rarely get snow, but small or modest snow accumulations can have substantial effects on mobility and work hours.

As seen in Table 10, columns 5-7, snow events provide the largest reductions in work hours in East South Central states such as Alabama and Tennessee. Each additional average daily inch of snowfall (an additional 7 inches over a week) is estimated to decrease weekly work by about 4.2 hours. The South Atlantic region has a coefficient of -2.6 and West South Central -2.7. By contrast, Table 10 shows that work hours in New England, the Mountain states, and East North Central states are least affected by snow, with snow level coefficients of -0.27, -0.37, and -0.44, respectively. These areas over the winter season may receive substantial snow on a single day, but rarely does this paralyze their communities. As discussed above, such communities have equipment, personnel, and supplies of salt and sand that allow them to handle large snowfalls. Workers and shoppers have adapted to winter travel conditions and are more likely to maintain their productive activities during winter storms.

VII. Conclusion

This research has examined the relationship between hour worked and weather conditions, specifically, how snowfall affects people's working hours. Extreme weather events may sharply reduce economic activity, but there is very limited evidence on the overall magnitude of these losses and how work hours respond to various levels of snow accumulation.

Table 10: The Relationship between hours worked last week and snowfall in different region

	(1) New England	(2) Mid-Atlantic	(3) East North Central	(4) West North Central	(5) South Atlantic	(6) East South Central	(7) West South Central	(8) Mountain	(9) Pacific
A. Snow is in the reference week (all data)									
Snow	-0.274***	-0.598***	-0.443***	-0.803***	-2.619***	-4.211***	-2.668***	-0.366	-0.498
	(0.0769)	(0.131)	(0.0973)	(0.220)	(0.377)	(1.104)	(0.402)	(0.213)	(0.405)
Observations	261,663	216,180	317,951	234,205	501,061	90,282	233,851	241,964	393,297
R-squared	0.190	0.169	0.188	0.183	0.125	0.153	0.137	0.135	0.137
B. Snow is in the reference week (snow event)									
Snow	-0.287***	-0.868***	-0.433***	-0.770***	-1.746***	-3.880***	-2.497***	-0.113	-0.298
	(0.0949)	(0.201)	(0.123)	(0.237)	(0.385)	(1.225)	(0.499)	(0.191)	(0.363)
Observations	85,228	59,202	167,665	118,584	31,412	21,285	42,975	65,741	91,616
R-squared	0.197	0.190	0.189	0.188	0.135	0.152	0.135	0.133	0.140

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: This table presents the estimated coefficient (and standard error), all robust standard errors are clustered at CBSA level in the parenthesis. There are total 18 regressions, and each regression controlled demographic information such as age, race, sex, educational level, experiences as well as five sets of dummies. Month dummies with October omitted, CBSAs size dummies with size 2 omitted; occupation dummies with "Management, Business, Financial" omitted; and industry dummies with "Agriculture, Forestry, Fishing, and Hunting" omitted.

The analysis in this study provides several pieces of evidence on how work hours are affected by winter snowfall. First, snowfall reduces work hours. On average, each additional inch of the average daily snow during a week reduces work time by about 1 hour. Second, higher levels of snow systematically lead to larger declines in work times. Third, we find systematic difference in worker response to snow events based on the type of worker (i.e., paid hourly or salaried), by class of employment (private sector, public sector, or self-employment), by industry of employment, by occupation, and by geographic region. And fourth, we find no compelling evidence that lost hours from snow storms are "made up" in the subsequent week or weeks. The possible exception is our finding of make-up hours two weeks following unusually severe snow storms (2 or more average daily inches of snow during a week). The apparent absence of work makeup effects reinforces the concern seen by the Federal Reserve Board and other economic analysts regarding the effect of winter storms on economic activity. Less clear is the aggregate magnitude of lost work hours from a typical winter.

Although we cannot provide a precise estimate of lost work hours and growth due to snow events, a back-of-the-envelope calculation is informative. Mean average daily inches of daily snow over the six "winter" months in our analysis is 0.125 inches. Multiplying the average inches by -0.9, the coefficient seen in our base equation in Table 3, column 1, we get -0.9 x 0.125 = -0.1125, indicating an average weekly reduction of 0.11 hours over the six winter months. Assuming that all snow effects occur during winter months, the average weekly reduction over twelve months is half as much, -.05625. Multiplying this by 52 weeks, we get an annual loss of an average 2.925 hours. Average total work hours, based on the 38 hours a week average in the CPS, is 1,976 hours. The 2.925 loss of hours represents a 0.0015 (2.925/1976) or 0.15 percent loss in annual hours worked. We assume the magnitude of labor input reduction will cause the equivalent reduction in economy-wide output. Given that average annual productivity growth has in recent years been only about 1.5 percent, a 0.15 percent annual reduction in work hours due to snowfall is nontrivial. Large year-to-year variations in levels of snow could well distort annual measures of growth rates, particularly so at a regional level. Given that snow effects are highly concentrated in time and location, it is not surprising that the Federal Reserve Board and business analysts often point to severe weather events as affecting short-run growth.

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Appendix 1: 21 Different Weather Types in GHCN-Daily Database

# of type	Description of the weather type
01	Fog, ice fog, or freezing fog (may include heavy fog)
02	Heavy fog or heaving freezing fog (not always distinguished from fog)
03	Thunder
04	Ice pellets, sleet, snow pellets, or small hail
05	Hail (may include small hail)
06	Glaze or rime
07	Dust, volcanic ash, blowing dust, blowing sand, or blowing obstruction
08	Smoke or haze
09	Blowing or drifting snow
10	Tornado, waterspout, or funnel cloud
11	High or damaging winds
12	Blowing spray
13	Mist
14	Drizzle
15	Freezing drizzle
16	Rain (may include freezing rain, drizzle, and freezing drizzle)
17	Freezing rain
18	Snow, snow pellets, snow grains, or ice crystals
19	Unknown source of precipitation
21	Ground fog
22	Ice fog or freezing fog