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Beyond the Annual Averages:

Impact of Seasonal Temperature on Employment Growth in US Counties

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ABSTRACT: Using quarterly temperature and employment data between 1990 and 2021, this paper uncovers nuanced evidence on the impact of seasonal temperature within US counties: higher winter temperature increases private sector employment growth while higher summer temperature decreases it. The impacts of higher temperature in mild seasons, fall and spring, are statistically insignificant. Moreover, the negative impact of higher summer temperature persists while the positive impact of higher temperature in the winter is more short-lived. The negative effects of a hotter summer are pervasive and persistent in many sectors: most significantly in "Construction" and "Leisure and Hospitality" but also in "Trade, Transport, and Utilities" and "Financial Activities." In contrast, the positive effects of a warmer winter are less pervasive. The employment effect of a hotter summer has been more severe in recent decades.

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WORKING PAPERS

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I. Introduction

Climate change is the biggest challenge for humankind. Temperature is rising. The global average temperature is already about 1.2 degree Celsius higher than the pre-industrial level. Droughts, wildfires, and massive storms are starting to occur more frequently with devastating effects. Understanding the impact of rising temperature, the most basic manifestation of climate change, on economic activity is fundamental to adaptation and mitigation efforts.

The economic literature has generally found that higher temperature hurts economic activity. Early literature examines the relationship between average temperature and aggregate economic variables (e.g., Sachs and Warner, 1997; Gallup, Sachs, and Mellinger, 1999). It finds that hotter countries tend to be poorer. However, this relationship might be driven by omitted variables such as country institutions. Recent literature uses fluctuations in temperature within a country or a region to control for slow-moving characteristics (see for example, Dell et al., 2012; Cashin et al., 2017; Colacito et al., 2019; Letta and Tol, 2019; Acevedo et al., 2020; Kahn et al., 2021).[1] It finds that higher temperature reduces the economic growth of poor countries (Dell et al., 2012; Acevedo et al., 2020) and the US (Colacito et al., 2019). The negative effects run through reduced total factor productivity growth (Letta and Tol, 2019), and reduced investment and labor productivity (Acevedo et al., 2020; Kalkuhl and Wenz, 2020). Burke et al. (2015) document the non-linear effect of temperature: economic growth rises with average annual temperature until around 13 degrees Celsius and drops after that.

This paper examines the dynamic effects of temperature on the private sector's employment growth at a local level, namely US county, and high frequency, namely quarterly. Going to the county and quarterly levels allows for more precise temperature measurement. Therefore, it could estimate the effects of temperature more precisely and uncover the subtle effect of seasonal temperature. This paper focuses on job growth as the main economic outcome. Jobs are featured prominently in the US's discussions of climate change mitigations. Many worry that climate change mitigation efforts will hurt jobs (AFP, 2022). This paper finds that higher temperature, on average, hurts jobs in the US.

Using data between 1990 and 2021, this paper discovers opposing effects of higher temperature in the winter and summer. On average, within a county, higher summer temperature reduces private sector employment growth, while higher winter temperature increases it. The impacts of higher temperature in mild seasons, fall and spring, are statistically insignificant. The findings showcase the heterogenous and nuanced effects of temperature shocks.

This paper finds interesting dynamic effects of seasonal temperature. Higher summer temperature hurts economic activity in the current and following quarters. A temporary one-degree Fahrenheit (F) higher summer temperature decreases year-over-year (YoY) employment growth of that summer by 0.063 percent. It also decreases YoY employment growth of the following fall and winter by 0.08 and 0.075 percent, respectively. In contrast, the positive impact of higher temperature in the winter is more short-lived. A temporary one-degree Fahrenheit warmer winter boosts YoY employment growth in that winter by 0.05 percent but has statistically insignificant effects on employment growth in the following spring and summer. In sum, the negative impacts of

[1] Also see recent surveys by Dell et al. (2014) and Auffhammer (2018)

higher temperature in the summer are larger and more persistent than the positive impacts of higher temperature in the winter. Therefore, the average employment effect of higher temperature across seasons is negative.

The economic literature typically examines the impact of annual average temperature on annual economic outcomes (e.g., see Deschênes and Greenstone, 2007; Dell et al., 2012; Burke et al., 2015; Acevedo et al., 2020; Kalkuhl and Wenz, 2020; Akyapi et al., 2022). However, since temperature can vary greatly within a year, from freezing winters to scorching summers, this paper argues that seasonal temperature is a better approximation of weather than annual temperature.[2] More importantly, the economic structures of different seasons could be very different. For example, construction, travel, and tourism are expected to rise in summer and fall in winter. Therefore, examining the effects of seasonal temperature on seasonal economic activity could offer new insights to complement the existing analyses using annual average temperature and annual-average economic outcomes. In addition, working with the country-average temperature is also not ideal since even within a country, temperature can vary greatly. A country, or even a US state, may have several climate zones. A case of localized temperature, such as at the county level, can be made here.

Nevertheless, granular analyses come with their challenges and issues. First, and the most obvious issue is the lack of high-frequency economic data at the local level. One reason why employment growth is chosen as the main variable of interest is that the US has reliable quarterly data at the county level (more on that in section III). The second, and more conceptual issue is labor mobility at the local level. At the country level, labor mobility is relatively restricted. At least in the short-run, workers have to stay in a country and try to find work with a temperature shock. But an analysis at the local level, such as US county, implies labor mobility is much less restricted. People could move in and out of a county to work in another county in response to a temperature shock. Therefore, the effects of temperature on employment with labor mobility can be larger than without.

Deryugina and Hsiang (2017) and Colacito et al. (2019) examine the impacts of seasonal temperature at US county and state levels, respectively. However, they still use *annual* economic outcomes, which could mask interesting dynamic effects of seasonal temperature. This analysis complements their analyses by not focusing on annual economic outcomes but on the high-frequency impact of temperature on quarterly employment growth in US counties. By adopting this local and high-frequency empirical framework together, it unveils novel and interesting dynamic effects of seasonal temperature. It could also shed light on the mechanisms by documenting the effects in each industry and how they propagate over the next quarters. In other words, by observing temperature's impacts on different sectors at a high frequency, instead of being diluted by the annual averages, the paper can provide additional insights into the mechanisms.

This paper finds that the negative effects of a hotter summer are pervasive and persistent in many sectors: most significantly in "Construction" and "Leisure and Hospitality" but also in "Trade, Transport and Utilities" and "Financial Activities." Employment growth in these sectors may get directly hit by rising temperature. It is also possible that some of the lower employment growth is indirectly affected due to input-output linkages between different sectors or the aggregate demand effect. For example, job growth in "Financial Activities" could be dampened due to a slower financial service demand from "Construction." In contrast, the positive effects of a

[2] For example, highest daily temperature in Washington D.C. (United States) in 2021 ranges from the mid-30s Fahrenheit in the winter to the mid-90s Fahrenheit in the summer. The average annual temperature for Washington D.C. is about 70-degree Fahrenheit. If we use this annual average of 70-degree Fahrenheit in our analyses, we might be mistaken that Washington D.C.'s weather is more moderate while in fact, it has a cold winter and a hot summer.

warmer winter are less pervasive, only in “Construction,” “Leisure and hospitality,” and “Natural Resources and Mining.” It is also more short-lived.

The richness of county-level data allows for the examination of the effect by US state – which is another important contribution. This paper discovers a relationship between the negative effects of a hotter summer with a state’s summer climate: hotter states have more severe negative impacts of higher summer temperature. Some cooler states (e.g., Alaska and Massachusetts) even benefit from the higher summer temperature. On the other hand, the relationship between the impact of higher winter temperature and a state’s winter climate is not as clear.

An important point of discussion is how would these findings on short-term responses help us predict the long-term responses to hotter climates? It has been argued that the short-run responses to temperature fluctuations are likely not the same as the long-run responses to climate change (see the discussion in Burke and Emerick, 2016, for example). This is a reasonable argument. First, the future magnitude of climate change is uncertain, depending on humankind’s mitigation efforts. In addition, there could be a role of adaptation. Adaptation efforts, such as more widespread use of drought-resistant seeds or air-conditioning, might soften the impact of rising temperature in the future. If so, the short-run impacts may overstate the long-run impacts of climate (see also Massetti and Mendelsohn, 2018). Conversely, the rising temperature may cause permanent effects on employment (such as emigration out of the hot areas). In that case, the short-term impacts of temperature fluctuation might understate the long-run impacts of climate change.

This paper contributes to this discussion with two sets of findings. First, a warmer winter helps economic activities, while a hotter summer hurts them. In addition, the negative effects of a hotter summer in hotter states are larger and more persistent. The findings suggest that colder regions or countries may benefit from climate change while hotter ones may be hurt without significant adaptation efforts. These heterogeneous effects present a challenge for a unified effort to fight climate change (whether they are global efforts or those in the US). Second, this paper discovers more severe impacts of summer temperature in the US in recent decades (2000-2009 and 2010-2021) than in 1990-1999. A one-degree Fahrenheit hotter summer in the 2010s reduces employment growth in the summer and the following fall by about 0.1 percent more than it did in the 1990s. This finding implies adaptation efforts in the US have not taken hold or significantly altered the effects of temperature shocks. This finding has implications for other countries. Even for the US, which is a developed country with good adaptation capacity and with a generally mild climate, we observe negative impacts of higher temperature in the summer. For poorer, hotter countries, the effects of rising heat, without significant adaptation efforts, are likely much more severe.

The paper is organized as follows. Section II presents a simple theoretical framework to motivate the empirical specification. Section III presents data and the main empirical specification. Section IV presents the main findings on the overall impacts. Section V presents the impact by the US state and patterns between the impact magnitude and a state’s climate. Sections VI and VII examine the sectoral impacts of a hotter summer and a warmer winter. Section VIII presents the effects by decade. Section IX presents robustness checks. Section X concludes.

II. A Theoretical Framework

This section presents a theoretical motivation for the empirical setup, where temperature can have both a growth effect and a level effect on employment. Inspired by the framework presented in Dell et al. (2012), I let employment in quarter q a function of the current quarter’s productivity and last quarter’s employment:

$$L_q = \theta_s e^{\phi_s T_q} A_q^{\rho_s} L_{q-1}^{\lambda_s} \quad (1)$$

where q denotes quarter, s denotes the season (i.e., summer, fall, winter, or spring). L_q, T_q and A_q are employment, temperature and productivity in quarter q. L_{q-1} is employment in the previous quarter. Employment in a quarter can be driven by the current quarter's productivity and employment in the previous quarter. Capital is omitted for simplicity. Employment at quarter q can depend on employment at quarter $q-1$ because hiring may take time.

$e^{\phi_s T_q}$ denotes the *level* effect of the quarter's temperature on employment. Employment can be affected by the quarter's average temperature. A positive/negative/zero ϕ_s implies that higher temperature has a positive/negative/zero level effect on employment.

Note that the parameters $\theta_s, \phi_s, \rho_s, \lambda_s$ are season specific. That is, the parameters are different for winter, spring, summer, and fall. For example, higher temperature may have different (or even opposite) level effects in the summer versus in the winter, hence ϕ_{summer} should be different to ϕ_{winter}.

Seasonal productivity growth is as follows:

$$\log(A_q) - \log(A_{q-4}) = g_s + \delta_s T_q + \omega_s T_{q-4} \quad (2)$$

Equation (2) states that seasonal productivity growth depends on this quarter's temperature as well as the temperature of the same season last year (4 quarters ago). δ_s and ω_s are also season specific. T_q, this quarter's temperature, could have a positive or negative effect on seasonal productivity growth. T_{q-4}, temperature of the same quarter in the previous year, may affect this quarter's productivity growth via two channels. First is the base effect. For example, a lower T_{q-4} could lower A_{q-4} , which boosts $\log(A_q) - \log(A_{q-4})$ due to the base effect. Second is the productivity transmission effect. A lower T_{q-4} could lower A_{q-4} which could instead depress seasonal productivity growth for the following year. Therefore, on the net, it is not clear that ω_s is expected to have a positive or negative value.

Equations (1) and (2) state that temperature could have a *level effect* on employment (via $e^{\phi_s T_q}$). It could also have a *growth effect* on employment via seasonal productivity growth specified in equation (2).[3]

Now, let's rearrange equations (1) and (2) to derive an empirical specification. For ease of exposition, let's start equation (1) for the summer

$$L_q = \theta_{summer} e^{\phi_{summer} T_q} A_q^{\rho_{summer}} L_{q-1}^{\lambda_{summer}} \quad (3)$$

and substitute $L_{q-1} = \theta_{spring} e^{\phi_{spring} T_{q-1}} A_{q-1}^{\rho_{spring}} L_{q-2}^{\lambda_{spring}}$ (note that since q is the summer, $q-1$ is the spring).

(3) becomes $L_q = \theta_{summer} e^{\phi_{summer} T_q} A_q^{\beta_{summer}} \left(\theta_{spring} e^{\phi_{spring} T_{q-1}} A_{q-1}^{\rho_{spring}} L_{q-2}^{\lambda_{spring}}\right)^{\lambda_{summer}}$ (4)

[3] Although humankind's green-house gas emissions influence global temperature, local temperature is considered exogenous to local economic activities.

Keep substituting $L_{q-2} = \theta_{winter} e^{\phi_{winter} T_{q-2}} A_{q-2}^{\rho_{winter}} L_{q-3}^{\lambda_{winter}}$ and $L_{q-3} = \theta_{fall} e^{\phi_{fall} T_{q-3}} A_{q-3}^{\rho_{fall}} L_{q-4}^{\lambda_{fall}}$ into (4) , we can see that (1) takes the following general form:

$$L_q = \theta e^{\phi_0 T_q} e^{\phi_1 T_{q-1}} e^{\phi_2 T_{q-2}} e^{\phi_3 T_{q-3}} A_q^{\sigma_0} A_{q-1}^{\sigma_1} A_{q-2}^{\sigma_2} A_{q-3}^{\sigma_3} L_{q-4}^{\mu} \quad (5)$$

(5) states that employment is a function of temperature and productivity of this quarter as well as those in the previous three quarters and employment of quarter $q-4$. Note that all parameters of (5) are season specific.

Similar, for the same season in the previous year (i.e., $q-4$):

$$L_{q-4} = \theta e^{\phi_0 T_{q-4}} e^{\phi_1 T_{q-5}} e^{\phi_2 T_{q-6}} e^{\phi_3 T_{q-7}} A_{q-4}^{\sigma_0} A_{q-5}^{\sigma_1} A_{q-6}^{\sigma_2} A_{q-7}^{\sigma_3} L_{q-8}^{\mu} \quad (6)$$

Subtract log of (5) by log of (6):

$$\Delta\log\,(L_q) = \sum_{\tau=0}^{3} \phi_\tau \Delta T_{q-\tau} + \sum_{\tau=0}^{3} \sigma_\tau \Delta\log\,(A_{q-\tau}) + \mu\Delta\log\big(L_{q-4}\big) \quad (7)$$

where $\Delta\log\,(L_q) = \log\big(L_q\big) - \log\,(L_{q-4})$ is year-over-year growth in employment; $\Delta T_{q-\tau} = T_{q-\tau} - T_{q-\tau-4}$ indicates year-over-year change in temperature; and $\Delta\log\,(A_{q-\tau}) = \log\big(L_{q-\tau}\big) - \log\,(L_{q-\tau-4})$ indicates year-over-year growth in seasonal productivity.

Substituting (2) into (7) yields:

$$\Delta\log\,(L_q) = \sum_{\tau=0}^{3} \phi_\tau \Delta T_{q-\tau} + \sum_{\tau=0}^{3} \sigma_\tau \big\{g_\tau + \delta_\tau T_{q-\tau} + \omega_\tau T_{q-\tau-4}\big\} + \mu\Delta\log\big(L_{q-4}\big) \quad (8)$$

Rearrange terms in (8) yields:

$$\Delta\log\,(L_q) = g + \sum_{\tau=0}^{3} \beta_\tau T_{q-\tau} + \sum_{\tau=4}^{7} \pi_\tau T_{q-\tau} + \mu\Delta\log\big(L_{q-4}\big) \quad (9)$$

where $g = \sum_{\tau=0}^{3} \sigma_\tau g_\tau$; $\beta_\tau = \phi_\tau + \sigma_\tau \delta_\tau$; $\pi_\tau = -\phi_\tau + \sigma_\tau \omega_\tau$. As before, all parameters are season specific (that is, they vary depending on whether the quarter q is summer, fall, winter, or spring).

I am interested in the coefficients $\beta_0, \beta_1, \beta_2, \beta_3$, representing the effects of temperature in this quarter and three quarters ago on this quarter's employment. In the empirical section, I will estimate $\beta_0, \beta_1, \beta_2, \beta_3$ for each season. T_{q-4} to T_{q-7} and $\Delta\log\big(L_{q-4}\big)$ are considered control variables.[4]

[4] As discussed, temperature between $q-4$ and $q-7$ has base effects as well as potential productivity transmission effects.

III. Data and Empirical Specification

Data

Employment data: Quarterly employment data between 1990 and 2021 at the US county level are from the US Census's Quarterly Census of Employment and Wages (QCEW). The Quarterly Census of Employment and Wages (QCEW) program publishes a quarterly count of (formal) employment and wages reported by employers covering more than 95 percent of US jobs, available at the county, metropolitan (MSA), state, and national levels by industry. Major exclusions from the dataset include self-employed workers, most agricultural workers on small farms, all members of the Armed Forces, elected officials in most states, most employees of railroads, some domestic workers, most student workers at schools, and employees of certain small nonprofit organizations. QCEW includes only about half of the U.S. agricultural sector's employment. Therefore, agricultural employment is not included in the analysis.

Data for all 50 US states plus Washington D.C are collected. Then year-over-year percent change in employment level at the county level is calculated. Growth in all private employment is chosen as the key outcome, but more disaggregated employment is also used to examine the mechanisms of the impacts. This analysis focuses on private employment rather than public employment because private employment has a much larger share in the US. In addition, growth in private employment is more likely to reflect the impacts of rising temperature. In contrast, growth in public employment could reflect adaptation efforts by county governments, which is not my focus.

Temperature data: Temperature data for the contiguous US states are from gridMET. gridMET is a dataset of daily high-spatial resolution (about 4 km, 1/24th degree) surface meteorological data covering the contiguous US from 1979-yesterday.[5] Temperature data for the two remaining states, Alaska and Hawaii, are from the global ERA5 dataset with larger grids (about 30 km). Via the platform Google Earth Engine, I collect *maximum* daily temperature data from GridMET between 1990 and the end of 2021, matching the time coverage of the employment data. However, ERA5 data are only available to July 9, 2020. Hence, temperature data for Alaska and Hawaii in this paper only go until Q2 of 2020. Then, temperature is averaged across grids within a county to construct daily temperature data at the US county level. Next, temperature is averaged across days to generate temperature at the quarterly frequency. Temperature is in Fahrenheit.

To match temperature data with quarterly employment data, this analysis denotes average temperature for Quarter 1 (from January to March) as winter temperature, the average temperature for Quarter 2 (from April to June) as spring temperature, the average temperature for Quarter 3 (from July to September) as summer temperature, the average temperature for Quarter 4 (from October to December) as fall temperature.

Precipitation data: Precipitation data are collected similarly to the way temperature data are collected. First, total daily precipitation data by grids are collected, then averaged across grids within a county and across the days within a season to generate seasonal average precipitation for each US county. Precipitation data for the contiguous US states between 1990 and end of 2021 are from gridMET, while precipitation data for Alaska and Hawaii's counties between 1990 and Q2-2020 are from ERA5.

[5] https://www.climatologylab.org/gridmet.html

Table 1 presents the summary statistics of the two sources of data. In terms of year-over-year quarterly employment growth within a county, the median and mean values indicate it grows at close to 1 percent annually between 1990 and 2021. The simple average temperature across counties is 48.9 degrees Fahrenheit (for Q1 or Winter), 74.8 degrees Fahrenheit (for Q2 or Spring), 84 degrees Fahrenheit (for Q3 or Summer), and 56.3 degrees Fahrenheit (for Q4 or Fall). The medians of seasonal temperature take similar values.

In terms of year-over-year change in seasonal temperature within a county, the mean and median values of changes in seasonal temperature do not indicate that temperature consistently trends up over time across seasons at the US county level. Examining the medians more closely to avoid extreme values may be more useful. The median values of YoY changes in winter and summer temperature between 1990 and 2021 are positive (0.1 degrees Fahrenheit and 0.057 degrees Fahrenheit per year, respectively). However, the median values of YoY changes in spring and fall temperature are negative (-0.0279 and -0.13 degrees Fahrenheit per year, respectively). These summary statistics showcase the heterogenous (and sometimes opposite) seasonal temperature changes across seasons. Unit-root tests of seasonal temperature in the county-quarterly panel reject the null hypothesis that seasonal temperature series within counties have unit roots.

Table 1: Summary Statistics

	Quarter	N	N of counties	Mean	Min	Median	Max
YoY Employment Growth (%)	Q1	96,726	3,141	0.937	-92.112	0.890	841.506
	Q2	96,747	3,141	0.936	-91.254	0.966	869.860
	Q3	96,717	3,141	0.890	-91.019	0.888	752.892
	Q4	96,657	3,141	0.946	-91.451	0.943	443.647
Temperature (Fahrenheit)	Q1 (Winter)	100,261	3,141	48.93	-14.04	48.80	83.13
	Q2 (Spring)	100,266	3,141	74.80	27.91	75.14	97.76
	Q3 (Summer)	100,242	3,141	84.09	44.26	84.49	107.84
	Q4 (Fall)	100,240	3,141	56.34	-3.28	56.25	85.41
Yoy change in seasonal temperature (Fahrenheit)	Q1 (Winter)	97,115	3,141	-0.1571	-18.79	0.1006	19.84
	Q2 (Spring)	97,121	3,141	0.0039	-11.73	-0.0279	11.70
	Q3 (Summer)	97,097	3,141	0.0080	-11.74	0.0573	12.14
	Q4 (Fall)	97,096	3,141	0.0689	-15.95	-0.1315	15.64

Empirical Specifications

The regressions are based on county-quarterly panel data. Based on the theoretical motivation in section II, the main empirical specification is as follows:

$$\Delta L_{q,c} = g + \sum_{\tau=0}^{3} \beta_\tau T_{q-\tau,c} + \sum_{\tau=4}^{7} \pi_\tau T_{q-\tau,c} + \mu \Delta L_{q-4,c} + fe_c + fe_q + \epsilon_{q,c} \quad (10)$$

where q denotes quarter, and c denotes county. $\Delta L_{q,c}$ denotes year-over-year quarterly employment growth (in percent) at the county level, for example, between this year's summer and last year's summer. $\Delta L_{q,c}$ can be growth in all private sector employment or growth in smaller sectors such as construction, leisure and hospitality, and financial activities. Since this is year-over-year quarterly employment growth, it takes care of seasonality.

$T_{q,c}$ denotes county c's temperature at quarter q, and $T_{q-\tau,c}$ captures temperature τ quarters ago. β_τ $(\tau = 0,1,2,3)$ captures the effects of temperature in this current quarter and the previous three quarters on year-over-year employment growth in this quarter. This specification is well adopted in the literature, for example by Dell et al. (2012) and Colacito (2019). It is also derived from simple theoretical motivation in Part II, which shows that equation (10) is sufficiently flexible to allow a growth effect and a level effect of temperature.

$\Delta L_{q-4,c}$ is a control variable. It denotes year-over-year quarterly private employment growth four quarters ago (the same quarter in the previous year). This control is derived from the theoretical motivation and is consistent with the literature (e.g., Colacito et al., 2019; Akyapi et al., 2022).

$T_{q-\tau,c}$ $(\tau = 4,5,6,7)$ denotes temperature 4 to 7 quarters ago. They are control variables.

fe_c denotes county fixed effects; fe_q denotes year-quarter fixed effects. Hence, this specification reflects the impact of temperature on employment growth within a county.

The regressions are weighted by the constant share (of national employment) of a county's private employment to give higher weights for more populous counties. This weighting is to give more populous counties larger weights. Standard errors $\epsilon_{q,c}$ are clustered at the state level.

IV. Main Findings

Annual Regressions

This section presents the impact of annual average temperature on YoY growth of annual average employment at the county level. Table 2 shows that within a county, the impact of annual average temperature on growth of annual average employment is negative but not statistically significant (p-value=0.208). As will be clear below, using annual average temperature and employment masks interesting impacts of seasonal temperature.

Table 2: Impact of Annual Average Temperature on YoY Growth of Annual Average Employment

YoY Employment Growth	(1) Year
Annual Average Temperature (y=0)	-0.0443
	(0.0348)
Annual Average Temperature (y=-1)	-0.0203
	(0.0253)
YoY Employment Growth (y=-1)	-0.0423
	(0.117)
Constant	4.969
	(3.343)
Observations	93,651
Number of counties	3,141
R-squared	0.275
County FE	yes
Year FE	yes

Standard errors in parentheses are clustered at the state level, *** p<0.01, ** p<0.05, * p<0.1. Regressions are weighted by the constant share of a county's private employment.

Main Findings

Table 3 shows the dynamic impact of temperature on year-over-year (all private) employment growth for each season (columns [1] to [4]) and for the whole sample (column [5]). The main variables of interest are temperature this quarter and up to three quarters ago. For example, regression (1) shows the impact of temperature for the current winter (Q1 of the current year), the previous fall (i.e., Q4 of the previous year), the previous summer (i.e., Q3 of the previous year) and the previous spring (i.e., Q2 of the previous year) on private employment growth in the current quarter (Q1 of the current year). The dynamic impact of a season's temperature can be picked up by collecting the coefficients across columns [1] to [4].

Table 3: Impact of Temperature on YoY Private Employment Growth

YoY Employment Growth	(1) Winter (Q1)	(2) Spring(Q2)	(3) Summer(Q3)	(4) Fall(Q4)	(5) Pooled
Key variables					
Temperature (current quarter)	0.048***	0.025	-0.063*	-0.017	0.015
	(0.017)	(0.034)	(0.036)	(0.02)	(0.015)
Temperature (q-1),	0.0082	0.0039	0.0017	-0.08***	-0.011
	(0.015)	(0.013)	(0.022)	(0.03)	(0.009)
Temperature (q-2),	-0.075***	-0.011	0.0069	-0.027	-0.022*
	(0.025)	(0.018)	(0.015)	(0.032)	(0.012)
Temperature (q-3),	-0.0086	0.0089	-0.00094	0.007	-0.0047
	(0.0137)	(0.0314)	(0.0304)	(0.0112)	(0.0088)
Control variables					
Temperature (q-4)	0.0022	-0.07***	-0.041**	-0.0084	-0.031***
	(0.0139)	(0.018)	(0.018)	(0.027)	(0.005)
Temperature (q-5),	-0.03	0.065***	-0.0037	-0.048**	-0.0053
	(0.0261)	(0.0103)	(0.0124)	(0.0209)	(0.0066)
Temperature (q-6),	-0.022	-0.093***	0.056***	0.032	0.0071
	(0.0234)	(0.0267)	(0.00785)	(0.0190)	(0.0064)
Temperature (q-7),	0.0016	-0.07**	-0.05	0.039***	-0.004
	(0.0137)	(0.0273)	(0.0302)	(0.0121)	(0.008)
YoY Employment Growth (q-4),	0.104***	-0.028	0.024	0.115***	0.049
	(0.028)	(0.081)	(0.061)	(0.028)	(0.0379)
Constant	yes	yes	yes	yes	yes
Observations	93,506	93,532	93,502	93,427	373,967
R-squared	0.372	0.554	0.457	0.443	0.468
Number of counties	3,141	3,141	3,141	3,141	3,141
County FE	yes	yes	yes	yes	yes
Year-Season FE	yes	yes	yes	yes	yes

Standard errors in parentheses are clustered at the state level, *** p<0.01, ** p<0.05, * p<0.1. Regressions are weighted by the constant share of a county's private employment. The dark gray highlights show the dynamic effects of summer temperature on summer and subsequent seasons. The light gray highlights show the dynamic effects of winter temperature.

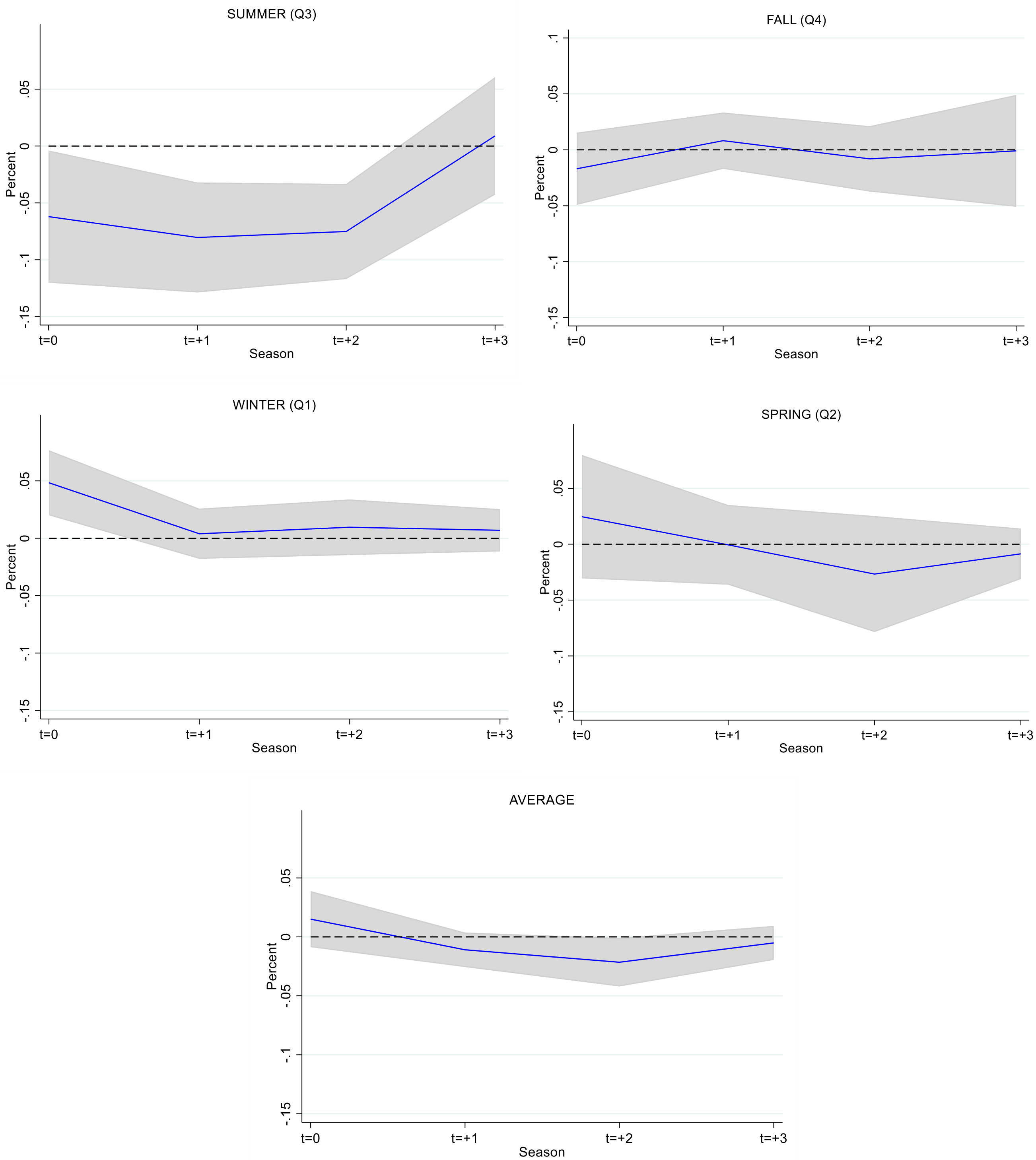
Figure 1 visualizes the same findings in 5 charts. The shaded areas represent 90% confidence intervals. Table 3 and Figure 1 reveal that the average effect of higher temperature in the US is small (column 5). However, the average effect masks large and opposing effects of higher temperature in different seasons. Temporarily higher summer (Q3) temperature hurts employment growth significantly and persistently. Higher temperature in a summer not only reduces YoY private employment growth in that summer but also YoY employment growth in the following fall and winter. The effect of a temporarily hotter summer dissipates in the following spring (see Figure 1). The coefficient of 0.063 (column 3) implies that a temporary one-degree Fahrenheit higher summer temperature decreases YoY employment growth of that summer by 0.062 percent. It also reduces YoY employment growth of the following fall and winter by 0.08 and 0.075 percent, respectively. To summarize, a temporarily hotter summer has temporary but persistent effects on employment growth. Therefore, it has a permanent effect on the employment level. Note that this finding is not driven by a possible correlation of temperature in the subsequent seasons because the temperature in the subsequent seasons is already controlled (see Table 3).

Temporarily higher winter (Q1) temperature helps employment growth, but only significantly so for the current winter. The coefficient of 0.048 (column 1) implies that a one-degree Fahrenheit warmer winter boosts YoY employment growth in that winter by 0.048 percent but has statistically insignificant effects on YoY employment growth in subsequent seasons. Temperature in the milder seasons, fall and spring, does not affect employment significantly. Their magnitude is also relatively small.

Note that the impact of a hotter summer is less precisely estimated than the impact of a warm winter. The 90% confidence interval is larger. As the next section shows, the impact of a hotter summer varies more across states. Some states are hit heavily by a hotter summer, while others benefit.

Since the negative employment effect of a temporary one-degree Fahrenheit hotter summer is larger and more persistent than the positive employment effect of a temporary one-degree Fahrenheit warmer winter, the aggregate effect across seasons is dominated by the summer effects (see column 5 and Figure 1). The average employment effect of a one-degree Fahrenheit higher temperature across all seasons is positive but insignificant for the current quarter. However, it turns negative and more statistically significant for the next three quarters, especially q+1 and q+2 (see Figure 1).

Figure 1: Dynamic Impact on YoY Employment Growth to a One Degree Fahrenheit Higher Temperature



Note: The charts show the dynamic employment growth effects of a one-degree Fahrenheit higher temperature. Winter = January to March(Q1); Spring = April to June(Q2); Summer=July to September(Q3); Fall=October to December (Q4). The shaded areas represent 90% confidence intervals. Standard errors are clustered at the state level.

V. Summer and Winter Impacts Across State's Climate

One of the important questions is how the impact varies with climate zones. The existing literature pointed out that the impact of higher temperature is more severe for hotter countries. This section tackles this question by examining how higher temperature in the summer and winter affects US states differently. In other words, how the impacts differ for hotter versus cooler states. The rich data at the county level allow going to this granular level, since each state has several counties.[6] This paper finds that higher summer temperature hurts employment growth in many US states, but most so in hotter states in the South, such as Arizona (AZ), New Mexico (NM), and Missouri (MS). Cooler states even benefit from a hotter summer. On the other hand, there is no clear relationship between the impact of higher winter temperature with a state's winter climate.

This analysis proceeds as follows. First, since a state has several counties, the baseline regression (10) is run for each state for the 50 states and the District of Columbia. Then the average impact of a one-degree Fahrenheit higher summer temperature in the current quarter and the next three quarters is calculated (which is the average of the 4 coefficients, like those highlighted in dark gray in Table 3). Panel A of Figure 2 shows the spatial distribution of the summer impact. The red color shows states with a more negative impact of a hotter summer, while the blue color shows states with a more positive impact of a hotter summer. Arizona (AZ) and New Mexico (NM) stand out as two states with large negative effects of a hotter summer, while Alaska and New England states look to benefit from a hotter summer.

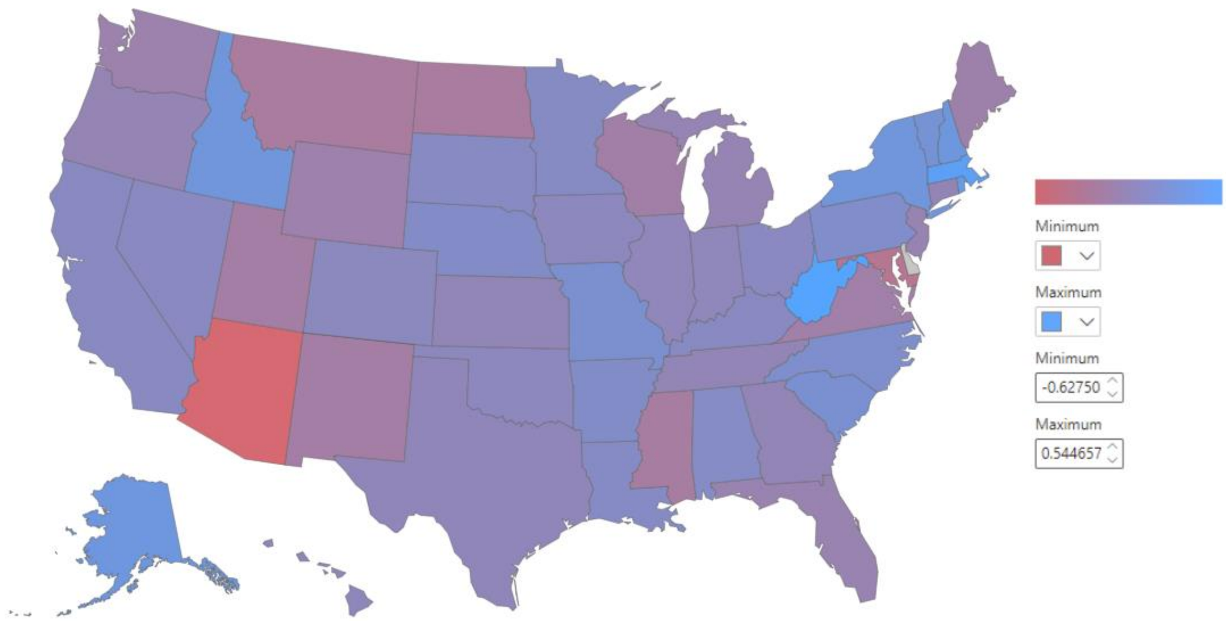
To examine the relationship between a state's summer climate and the summer impact, in Panel B of Figure 2, I plot the average summer impact against a state's average summer temperature (between 1990 and 2021). The scatterplot is shown with constant state-level employment weights (panel B1). For readers' reference, state names are provided in panel B2. Note that the scatterplots exclude Delaware, which has only three counties, and the District of Columbia due to imprecise estimates.[7] Panel B shows a downward-sloping relationship between the average employment growth impact in the subsequent four quarters and a state's summer climate. Hotter states have a more severe negative employment impact of a hotter summer. Employment growth in many cool states (Alaska (AK), Vermont (VT), and New Hampshire (NH)) benefit from a hotter summer. How each state loses or benefits from a hotter summer is a topic for future research.

[6] The granular analysis for each state would be impossible with another unit of analysis, such as commuting zone.

[7] The estimates of a one-degree Fahrenheit hotter summer for Delaware and Washington D.C. are -0.9 and -1.26, respectively.

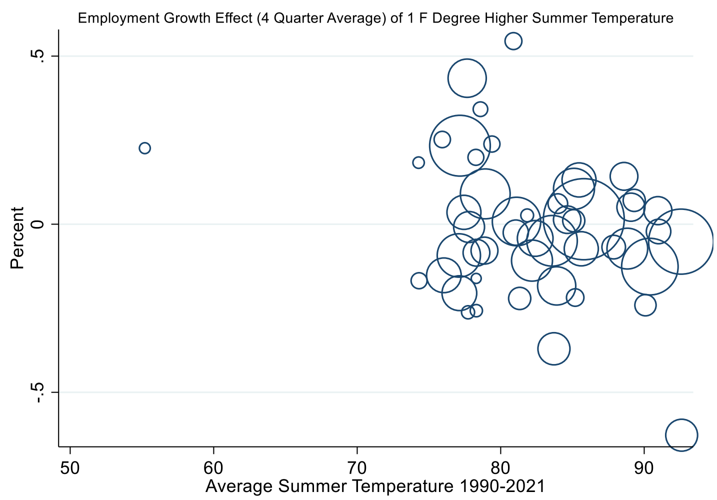
Figure 2: Average Summer Impact by State

Panel A: Spatial distributions of the summer impact

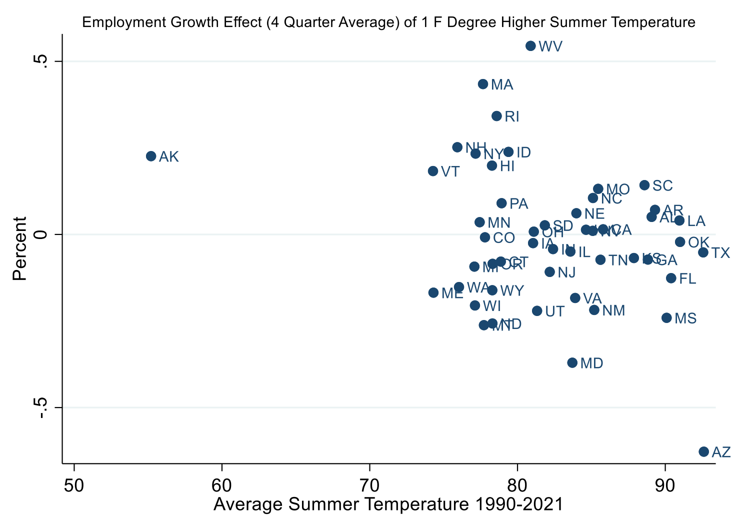


Panel B: Summer impact and a state's summer climate

Panel B1: With state's constant employment share



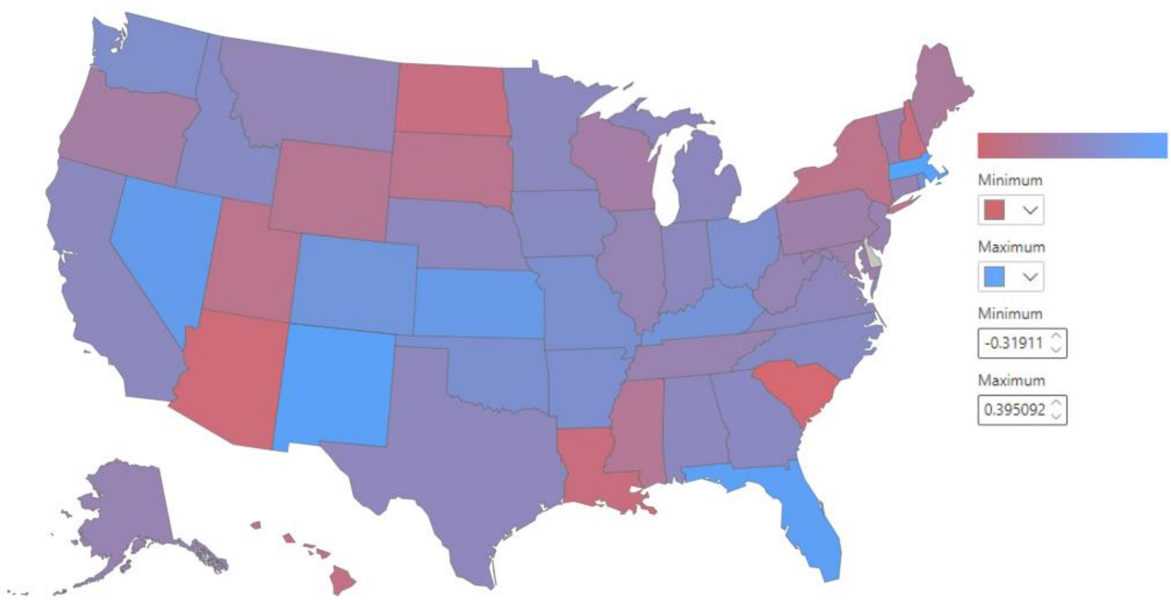
Panel B2: With state names



Note: The charts show the employment growth effects of a one-degree Fahrenheit hotter summer. The vertical axis is the average employment growth impact for the subsequent four quarters (t=0 until t=+3). The scatterplot excludes Delaware and Washington DC because of imprecise estimates (Delaware has only three counties; Washington DC has one).

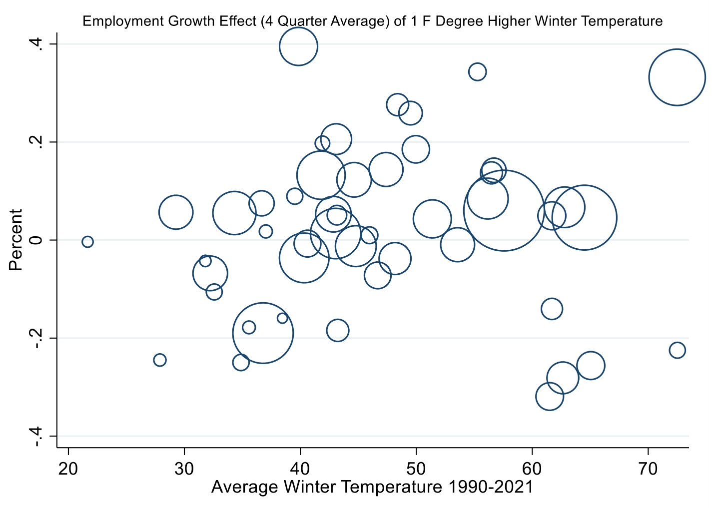
Figure 3: Average Winter Impact by State

Panel A: Spatial distributions of the winter impact

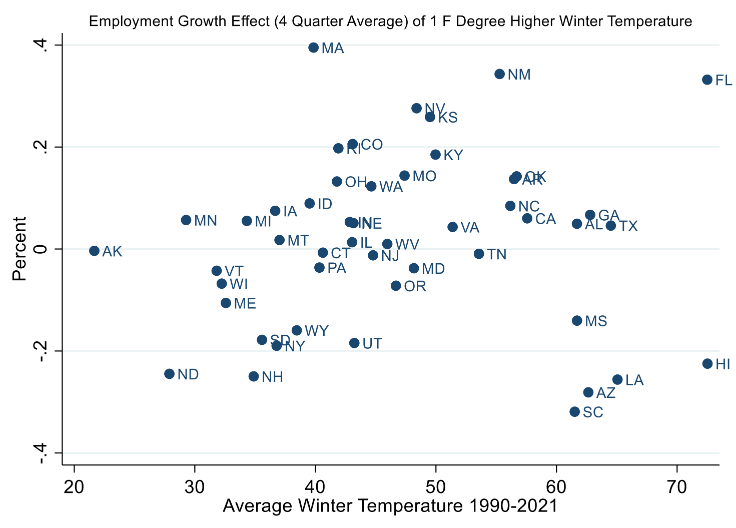


Panel B: Winter impact and a state's winter climate

Panel B1: With state's constant employment share



Panel B2: With state names



Note: The charts show the employment growth effects of a one-degree Fahrenheit warmer winter. The vertical axis is the average employment growth impact for the subsequent four quarters (t=0 until t=+3). The scatterplot excludes Delaware and Washington DC because of imprecise estimates (Delaware has only three counties; Washington DC has one).

Similarly, the average impact of higher winter temperature on private employment growth in the current quarter and the next three quarters is calculated. Panel A of Figure 3 shows the spatial distribution of the winter impact. The red color shows states with more negative impacts of a warmer winter, while the blue color shows states with more positive impacts. There does not seem to be a particular pattern in the spatial distribution. Florida stands out as a clear beneficiary of a warm winter, possibly due to the better attraction of its warmer beaches and other tourist destinations.

To examine a potential relationship between a state's winter climate and the winter effect, I plot the average employment impact against the average winter temperature between 1990 and 2021. The scatterplot is shown in panel B1 of Figure 3. In addition, state names are provided in panel B2 of Figure 3. Panel B1 shows a flat relationship between the average employment growth impact and a state's winter climate.

Table 4 presents regressions to formalize the relationship shown in Panels B1 of Figures 2 and 3. In the first case, the finding is robust with or without a potential outlier (Alaska (AK)). The regressions confirm a significant linear relationship: states with higher average summer temperature have more negative average employment effects. In the second case, there is no relationship between a state's winter climate and the winter effect.

Table 4: Relationship between Employment Effect and a State's Climate

VARIABLES	Average Employment Effect of one-degree Fahrenheit hotter summer		Average Employment Effect of one-degree Fahrenheit warmer winter
	Including Alaska (AK)	Excluding Alaska (AK)	
Average Summer Temp (1990-2021)	-0.0110*	-0.0111*	
	(0.0055)	(0.0059)	
Average Winter Temp (1990-2021)			0.00292
			(0.00290)
Constant	0.906*	0.919*	-0.104
	(0.468)	(0.498)	(0.143)
Observations	49	48	49
R-squared	0.120	0.116	0.051

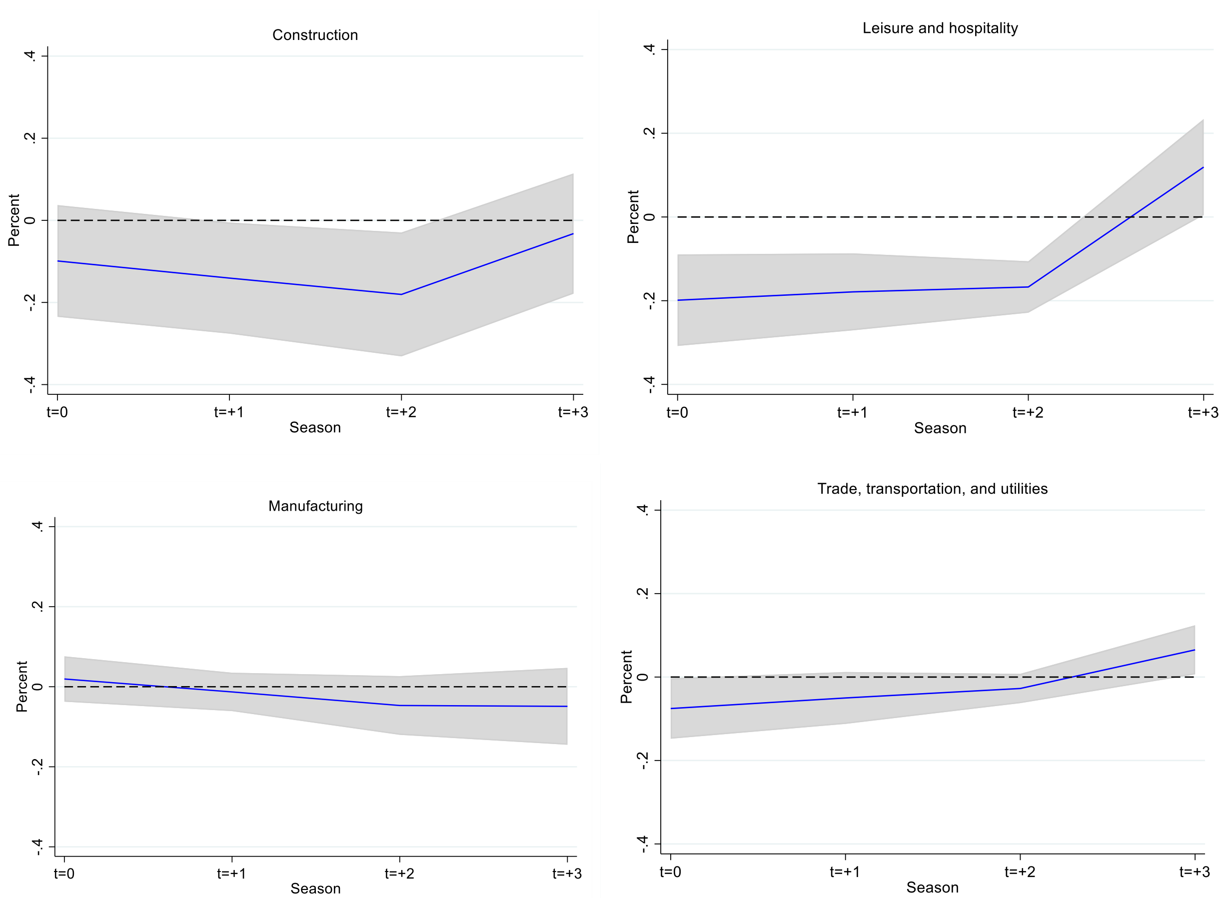
Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Regressions are weighted by the constant share of a state's private employment. The regressions exclude Delaware and Washington, D.C. because of imprecise estimates (they are small states with few counties).

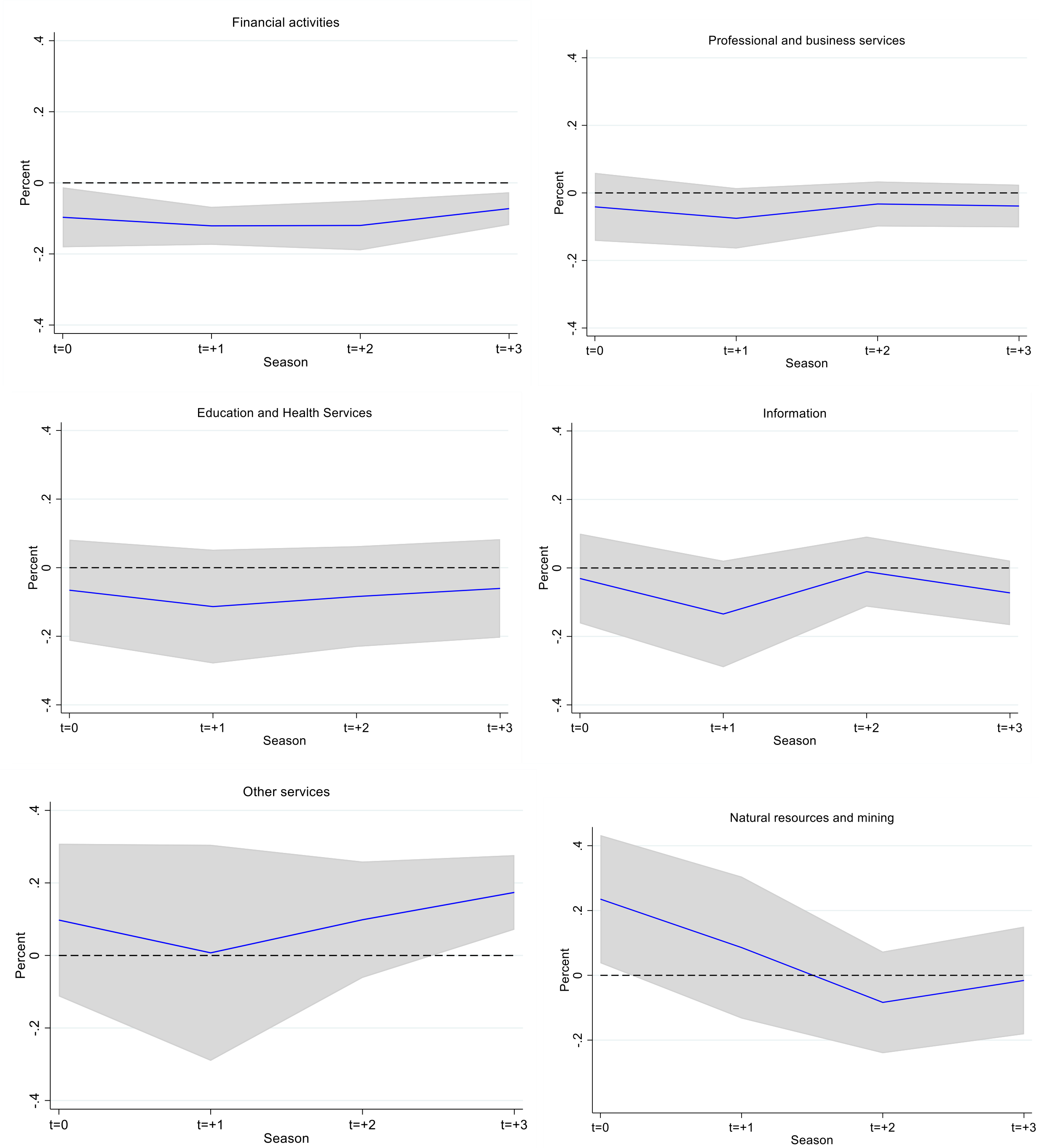
VI. On the Mechanisms of the Summer Temperature Effects

This section examines the mechanisms of the summer temperature effects by estimating the dynamic effects by sectors. Figure 4 shows that "Construction" (NAICS code 1012), "Leisure and Hospitality" (NAISC code 1026), "Trade, Transportation and Utilities" (NAICS code 1021), and "Financial Activities" (NAICS code 1023) are the hardest hit. This finding makes sense because "Construction" and "Leisure and Hospitality" are most exposed to outside heat. Employment growth in these sectors for subsequent quarters is also hit for two possible reasons. First, the activity could be autocorrelated across seasons. For example, fewer construction starts in the summer can reduce construction employment in the fall. Second, an overall decline in economic activity in the subsequent seasons can affect these sectors (the aggregate demand effects).

Services are less unaffected. However, employment growth in “Financial activities” (NAICS code 1023) is hurt. This finding is interesting because workplaces for financial sectors are generally climate-insulated. One explanation is that lower employment growth in other sectors could hurt employment growth in financial activity, driven by the decline in the demand for financial services. For example, declines in construction activities could depress demand for financial services. Affected to a lesser extent are employment growth in “Trade, Transportation and Utilities” and “Professional and business services” (NAICS code 1024). Note that “Construction,” “Trade, Transportation and Utilities,” and “Leisure and Hospitality” have large employment shares (see Figure 6). “Manufacturing” is not affected contemporaneously (probably because it is mostly indoor). A sector that benefits from a hotter summer is “Natural Resources & Mining.” However, it has a very small employment share (see Figure 6).

Figure 4: The Effect on Employment Growth of Higher Summer Temperature by Sector



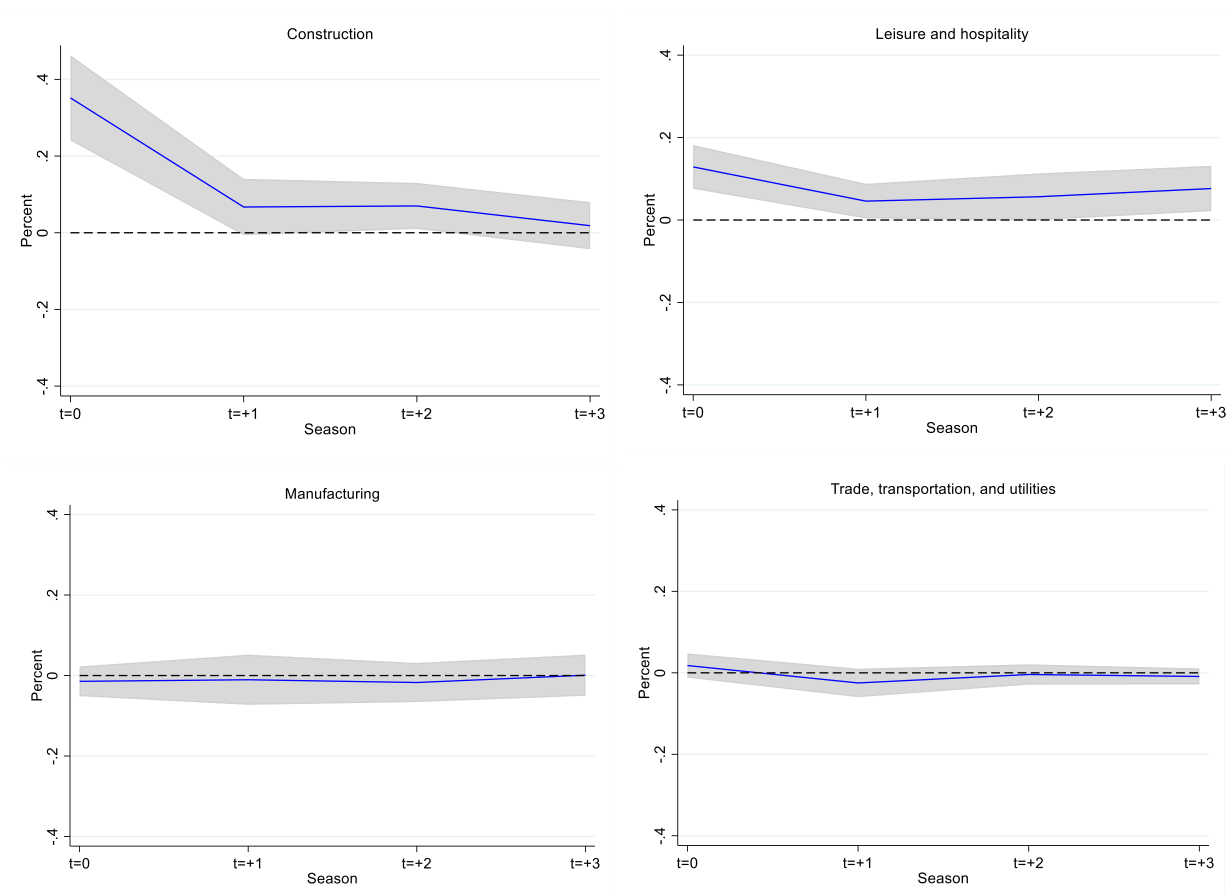


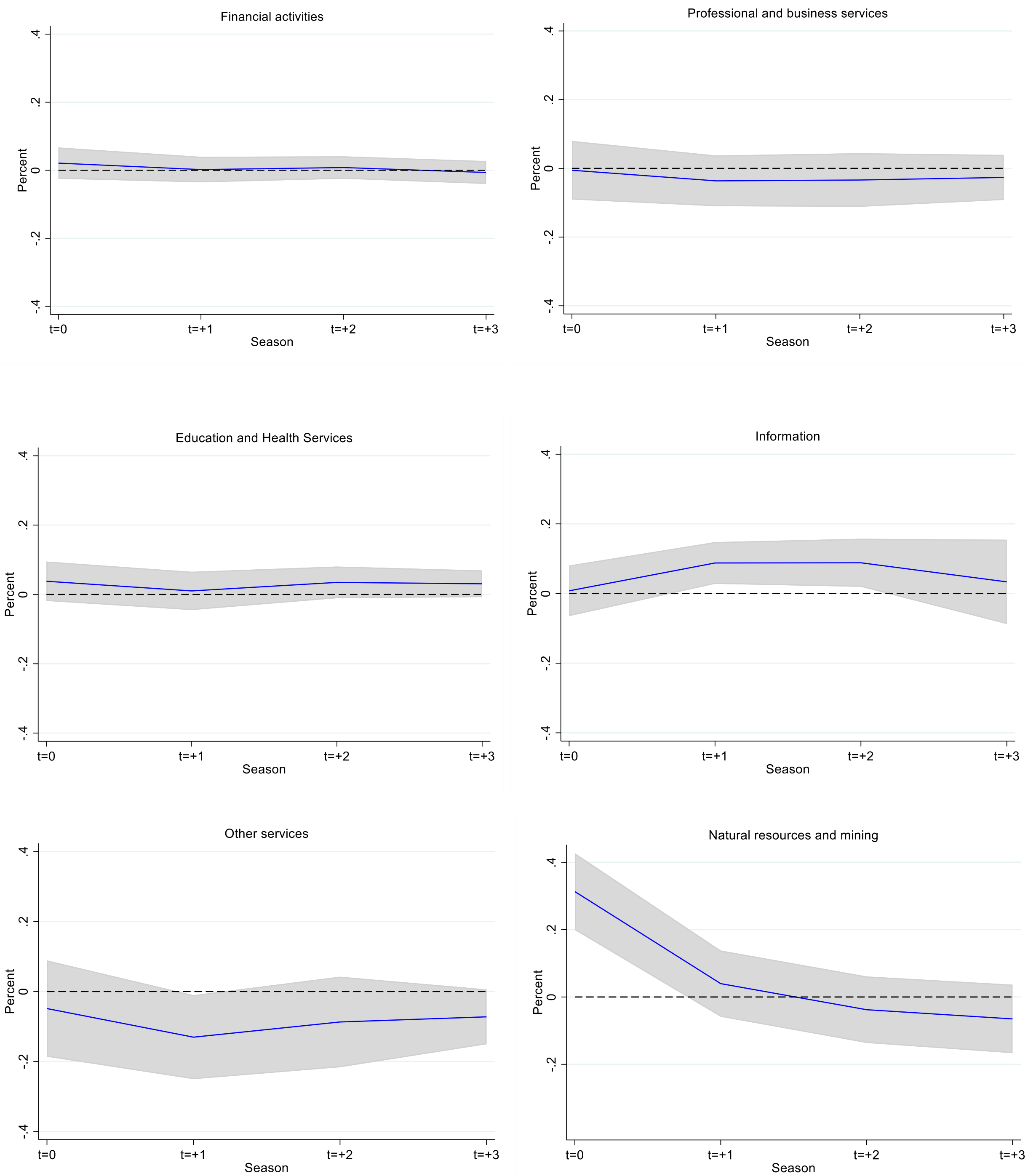
Note: The charts show the dynamic employment growth effects of a one-degree Fahrenheit hotter summer by sector. The shaded areas represent 90% confidence interval. Standard errors are clustered at the state level.

VII. On the Mechanisms of the Winter Temperature Effects

The sectors that benefit from a warmer winter are “Construction,” “Leisure and hospitality,” and “Natural Resources and Mining.” No sector is significantly hurt by a warmer winter. However, it is interesting to note that the effect of a warmer winter is less pervasive than the effect of a warmer summer. Only three sectors are significantly affected.

Figure 5: The Effect of Higher Winter Temperature by Sector

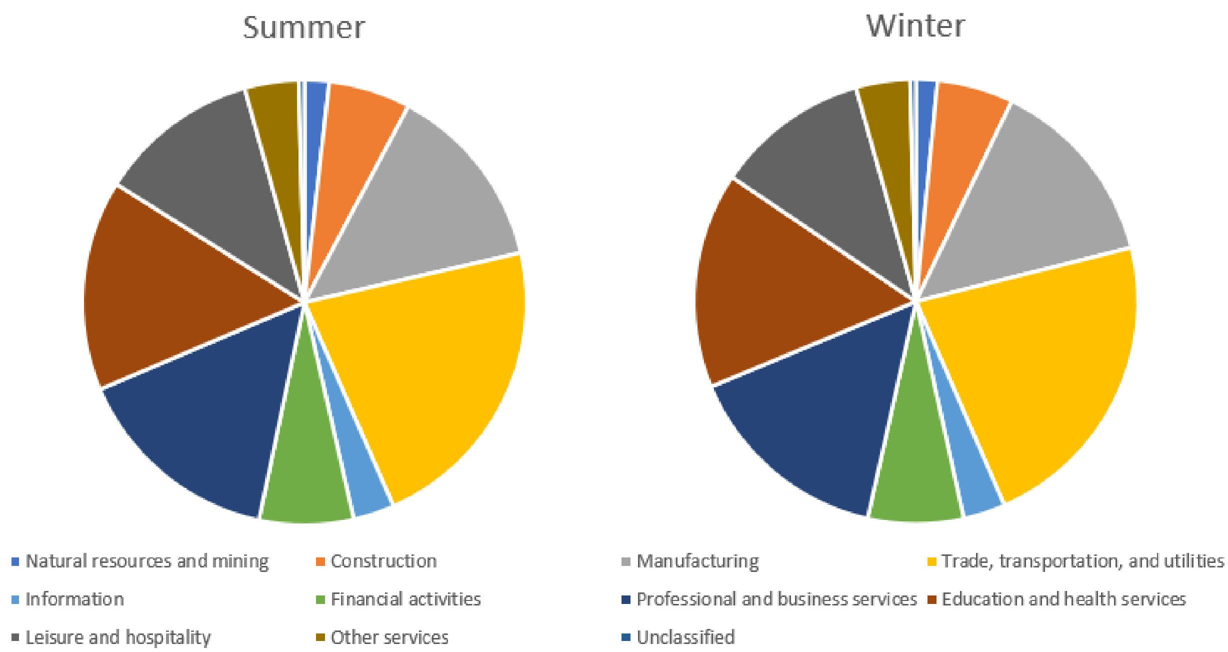




Note: The charts show the dynamic employment growth effects of a one-degree Fahrenheit warmer winter by sector. The shaded areas represent 90% confidence intervals. Standard errors are clustered at the state level.

The positive effect on "Construction" is more short-lived than the case of the summer. While the effect for the current quarter is very large, the spillover to employment growth in the spring and summer is small (see Figure 5). This finding could be because housing projects do not typically start in the winter. Employment in construction is, on average, the highest in the summer (11% more than that in the winter). Similarly, the spillover effects of a one-degree Fahrenheit warmer winter for “Leisure and hospitality” in subsequent seasons are also small. Other sectors that have persistent negative impacts from a hotter summer (such as “Financial activities,” “Trade, transportation, and utilities”) do not have such persistent positive effects from a warmer winter. These sectors have large employment shares (see Figure 6). These findings explain why the employment growth effect of a warmer winter, as shown in Figure 1, is short-lived.

Figure 6: Average Employment Shares in the Summer and Winter in a County



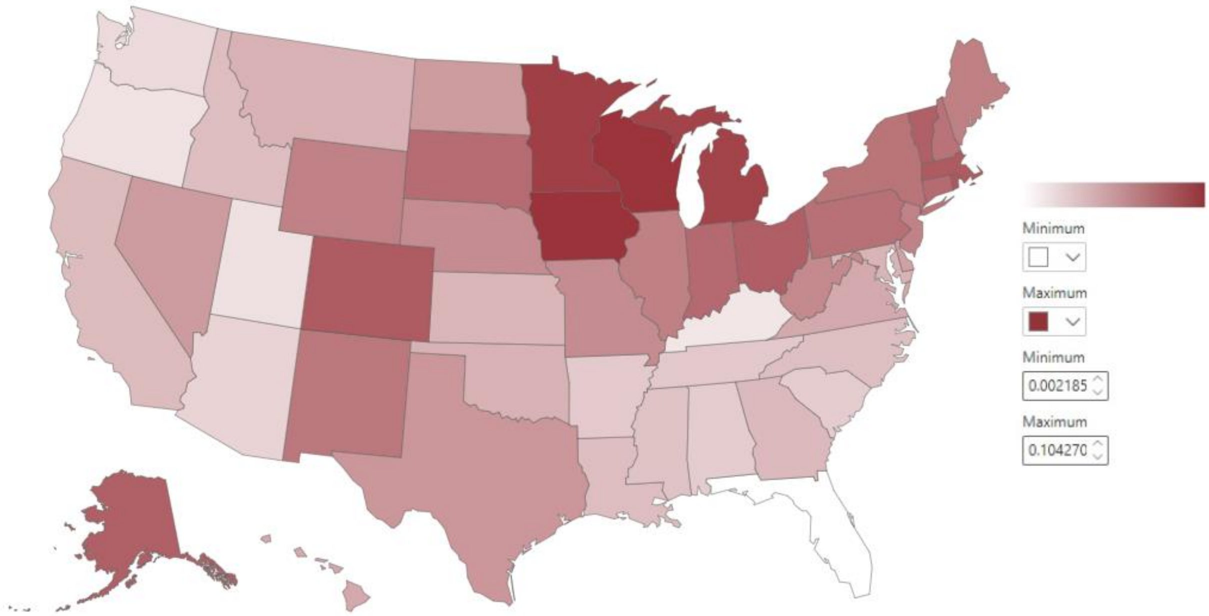
VIII. Effects of Temperature by Decade

This section examines the effects of long-term climate changes, which occur at different rates for different countries and regions. For example, Figure 7 shows the US state's average annual summer temperature increase. I obtain this estimate by running the following regression for each state

$$T_c = \beta_0 + \beta_s year + fe_c + \epsilon_c \quad (2)$$

where T_c is *seasonal* temperature (e.g., summer) for county c, $year$ is time trend. fe_c is county fixed effects. β_s is the state-level annual increase in the season temperature. Figure 7 below shows state-average annual increase in summer temperature between 1990 and 2021. It ranges from 0.0022 F-degree to 0.1 degrees Fahrenheit yearly (or 3 degrees Fahrenheit over 30 years). The states with the most dramatic increases are colder in the North (Alaska, Wisconsin, Minnesota, North Dakota, and South Dakota). However, some hot states in the South (Texas, New Mexico) also see substantial temperature increases. The range of the increase in the summer temperature is consistent with the summary statistics shown in Table 1.

Figure 7: Average Annual Increase in Summer Temperature by State over 1990 and 2021



An important point of discussion is how would the findings on short-term responses help us predict the long-term responses to a hotter climate? It has been argued that the short-run responses to temperature fluctuations are likely not the same as the long-run response to climate change (see the discussion in Burke and Emerick, 2016, for example). For example, adaptation efforts, such as more widespread use of drought-resistant seeds or air-conditioning, might soften the impact of rising temperature in the future. If so, the short-run impacts may overstate the long-run impacts of climate. Conversely, the rising temperature may cause permanent effects on employment (such as emigration out of the hot areas). In that case, the short-term impacts of temperature fluctuation might understate the long-run impacts of climate change.

This paper contributes to this discussion by examining the short-term impacts by decade. We do so by interacting the temperature variables with decadal dummy variables. The point is to compare the dynamic effects of temperature over time (1990-1999; 2000-2009; 2010-2021). The argument is that if the effects of temperature, especially the negative effects of the summer temperature, are weaker in recent decades, this implies some degree of adaptation has been conducted to respond to a temporarily hotter summer.

This paper finds that a hotter summer's negative impact gradually worsens. First, the negative impact of a hotter summer is also worse during 2000-20 than during 1990-1999 (the baseline). Table 5 shows the interaction between the temperature variables with the 2000–2009-decade dummy and the 2010–2021-decade dummy. The interaction between the summer temperature and the 2000–2009-decade dummy is negative but not statistically significant (-0.0718 in column 3 and -0.0838 in column 4).

Table 5: Impact of Temperature by Decade

Yoy Employment Growth	(1) Winter	(2) Spring	(3) Summer	(4) Fall	(5) Pooled
Temperature (0)	0.119***	0.0415	0.0105	-0.0554*	0.0175
	(0.0418)	(0.0505)	(0.0576)	(0.0330)	(0.0205)
Temperature (q-1)	-0.102**	0.0503	0.0252	-0.00420	-0.00964
	(0.0386)	(0.0412)	(0.0294)	(0.0474)	(0.00860)
Temperature (q-2)	-0.0649	-0.0884*	0.0446	-0.0378	-0.0255
	(0.0464)	(0.0453)	(0.0346)	(0.0361)	(0.0175)
Temperature (q-3)	0.0547***	0.0618	-0.0875*	0.0205	-0.00319
	(0.0159)	(0.0609)	(0.0497)	(0.0244)	(0.00975)
Temperature (0)*2000-2009 decade	-0.112**	-0.0482	-0.0718	0.0755*	-0.000768
	(0.0428)	(0.0378)	(0.0623)	(0.0447)	(0.0117)
Temperature (q-1)*2000-2009 decade	0.193***	-0.0659	-0.0317	-0.0838	0.000449
	(0.0482)	(0.0527)	(0.0390)	(0.0555)	(0.00569)
Temperature (q-2)*2000-2009 decade	0.0153	0.133**	-0.0581	0.0160	0.00586
	(0.0569)	(0.0639)	(0.0473)	(0.0373)	(0.0104)
Temperature (q-3)*2000-2009 decade	-0.108**	-0.0393	0.120*	-0.0405	-0.0104
	(0.0464)	(0.0486)	(0.0601)	(0.0318)	(0.00866)
Temperature (0)*2010-2021 decade	-0.0920**	0.00322	-0.104**	0.0483	-0.00476
	(0.0445)	(0.0466)	(0.0426)	(0.0453)	(0.00977)
Temperature (q-1)*2010-2021 decade	0.166***	-0.0703	-0.0151	-0.102***	-0.00251
	(0.0469)	(0.0565)	(0.0356)	(0.0351)	(0.00469)
Temperature (q-2)*2010-2021 decade	-0.0416	0.135**	-0.0585	0.0266	0.00427
	(0.0425)	(0.0668)	(0.0472)	(0.0279)	(0.00890)
Temperature (q-3)*2010-2021 decade	-0.0638*	-0.101*	0.133**	-0.0103	0.00371
	(0.0381)	(0.0555)	(0.0575)	(0.0358)	(0.00833)
Temperature (q-4 to q-7)	Yes	Yes	Yes	Yes	Yes
Employment Growth (q-4)	Yes	Yes	Yes	Yes	Yes
Constant	yes	yes	yes	yes	yes
Observations	93,506	93,532	93,502	93,427	373,967
R-squared	0.376	0.555	0.460	0.445	0.468
Number of counties	3,141	3,141	3,141	3,141	3,141
County FE	yes	yes	yes	yes	yes
Year-Season FE	yes	yes	yes	yes	yes

Standard errors are clustered at the state level and in parentheses *** p<0.01, ** p<0.05, * p<0.1. Regressions are weighted by the constant share of a county’s private employment.

Second, the negative impact of a hotter summer is much worse during 2010-2021 than during 1990-1999 (the baseline). The interaction between the summer temperature and the 2010–2021-decade dummy is negative and statistically significant (-0.104 in column 3 and -0.102 in column 4). The first coefficient means that a one-degree Fahrenheit hotter summer in 2010-2021 reduces summer employment growth by 0.1 percent more than it did in the 1990-1999 decade. The second coefficient means a one-degree Fahrenheit hotter summer during

2010-2021 reduces employment growth in the following fall by 0.1 percent more than it did in the 1990-1999 decade. A hotter summer also hurt employment growth in the following winter and spring, but the effects are weaker and less statistically significant.

The evidence of a worsening impact of higher summer temperature in the US indicates a limited degree of adaptation to fluctuations in summer temperature or its limited impact. Logically, between different seasonal temperature, the hotter summer poses the most substantial challenges to economic activity. Therefore, if one thinks adaptations have been effective, one expects that the impact of a temporary one-degree Fahrenheit higher summer temperature would be smaller over time due to adaptation efforts.

In addition, there is a more positive impact of a warmer fall (Q4) on employment growth in recent decades than during 1990-1999 (the baseline), not only for that fall but also for subsequent seasons. The interactions between the temperature variables with the 2000-2009 and the 2010-2021 dummy variables are positive and largely statistically significant. On the other hand, a warm winter (Q1) 's positive impact has been dampened in recent decades. The four interactions between the temperature variables with the 2000-2009 dummy variable are negative, but only one interaction is statistically significant. Similarly, one of four interactions between the temperature variables with the 2010-2021 dummy variable is statistically significant. It is not clear why the impacts of fall (Q4) and winter (Q1) temperature have moved in opposite directions in recent decades.

IX. Robustness Checks

Not Using County Employment Weights

This section provides a robustness check to the main findings where the empirical regressions are not weighted by a county's employment. Note that the baseline regressions are weighted by the (long-term average) constant share of a county's employment to give higher weights to more populous counties. This approach is standard in the literature. Nevertheless, this section shows that the baseline results are robust without the employment weights. In other words, giving all counties the same weight regardless of their employment size does not change the main finding.

Figure 8: Dynamic Impact of YoY Employment Growth to a One Degree Fahrenheit Higher Temperature (Regressions are Unweighted)

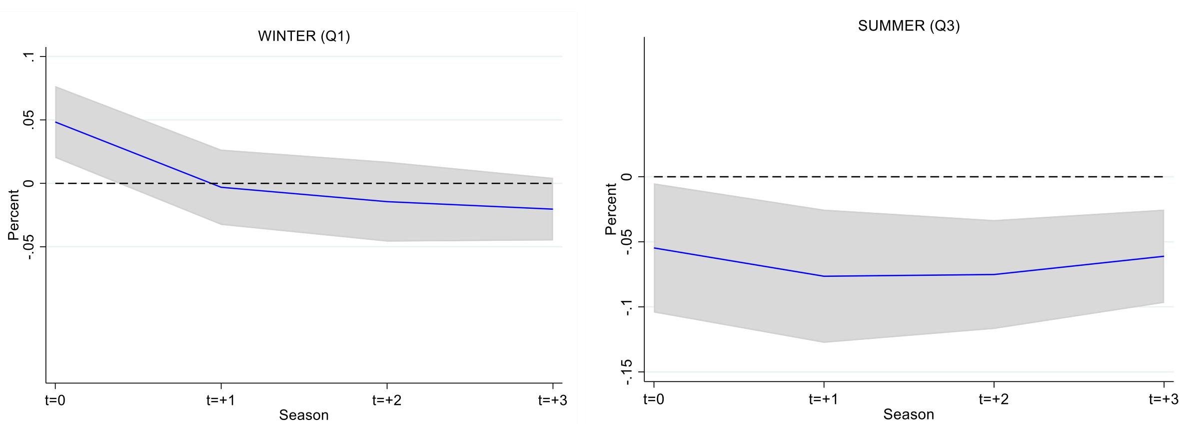


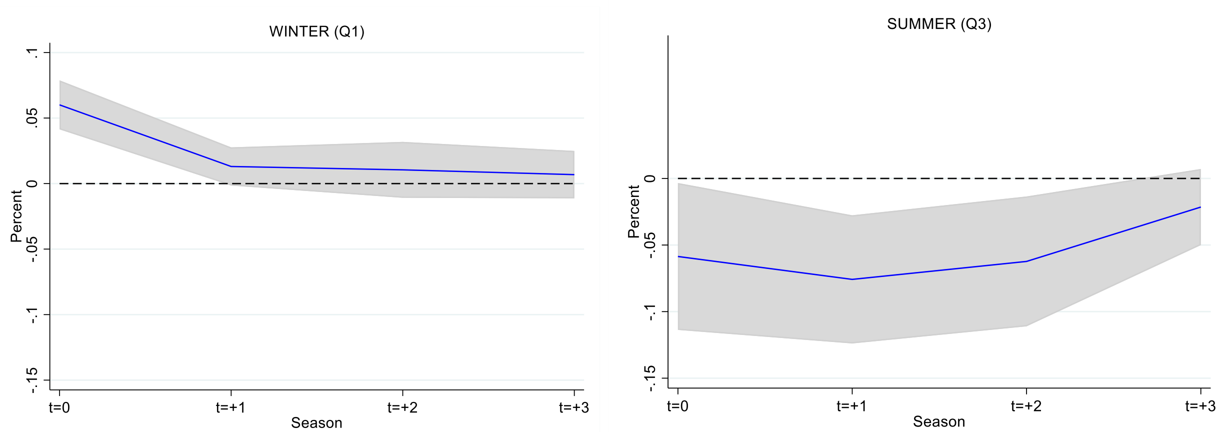
Figure 8 presents the dynamic impact of winter and summer temperature without county employment weights. It shows that the impact of a one-degree Fahrenheit higher summer temperature persists in subsequent quarters, while the effects of a one-degree Fahrenheit higher winter temperature are more short-lived.

Dropping Extreme Employment Growth

This section provides a robustness check to the main findings when counties and quarters with extreme employment changes are dropped. A potential concern is that extreme employment changes in a county and quarter could be caused by events that are not directly related to temperature of that year. An example is a plant opening or closing. To the extent that the extreme employment changes could be uncorrelated to temperature of the quarter, dropping them might not change the estimates of temperature's effects.

I drop YoY employment growth at the county-quarter level in the top and bottom one percentile of the distribution (i.e., those larger than 20.56 percent - the 99-percentile threshold- and those smaller than -17.27 percent- the 1-percentile threshold in the data). Note that temperature data of these observations are not dropped. Only employment growth data are. The dynamic impacts on YoY employment growth to a one-degree Fahrenheit higher summer temperature, and a one-degree Fahrenheit winter temperature remain similar to the baseline findings (see Figure 9).

Figure 9: Dynamic Impact on YoY Employment Growth to a One Degree Fahrenheit Higher Temperature (Top and Bottom 1 percentile of Employment Growth Data are Dropped)



Dropping Recession Quarters

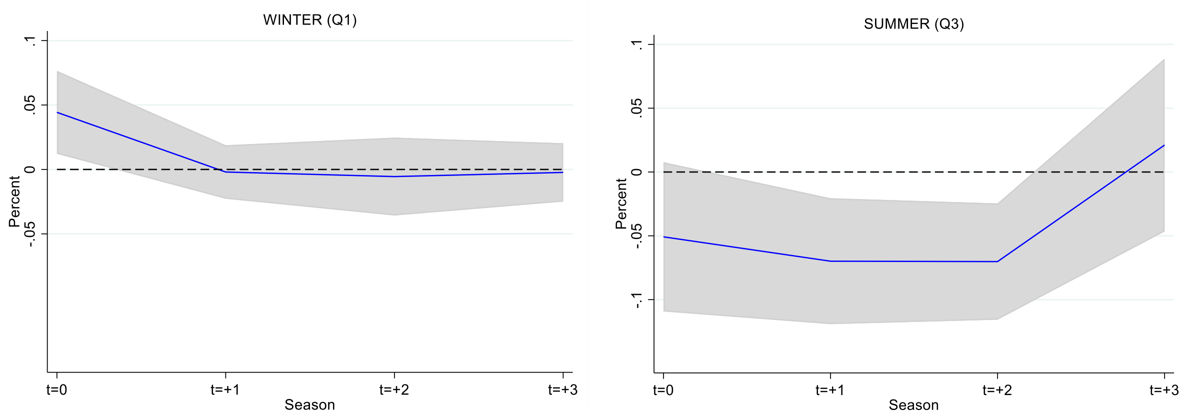
This robustness check drops YoY employment growth for quarters defined by the NBER as recessions. They are Q3 and Q4 of 2002; 2008 and Q1 and Q2 of 2009; Q2 of 2020.[8] Like the idea of the robustness above, employment growth in these quarters is arguably caused by reasons unrelated to temperature shocks. Notably,

[8] See https://fred.stlouisfed.org/series/USREC

the baseline specification captures the aggregate effects of these economy-wide shocks by the year-quarter fixed effects. Nevertheless, the recessions could have county-specific effects, depending on county employment composition. Counties with more demand-elastic industries (such as tourism) could be disproportionately affected by the recessions. In the unlikely scenario that temperature in these counties moves systematically and yields the same effects as the recession, the effect of temperature could be contaminated. For example, employment growth in counties heavily dependent on tourism might be more severely hurt by recessions. At the same time, if the summer temperature happens to also rise in these counties, the negative effects of hotter summer temperature on summer employment growth might be contaminated by the recessions.

Figure 10 presents the dynamic impacts on employment growth after employment growth data for these recessionary quarters are dropped. Note that temperature data for these quarters are not dropped. Again, the impacts remain robust and similar to the baseline findings in Figure 1.

Figure 10: Dynamic Impact on YoY Employment Growth to a One Degree Fahrenheit Higher Temperature (Employment Growth Data for Recessionary Quarters are Dropped)



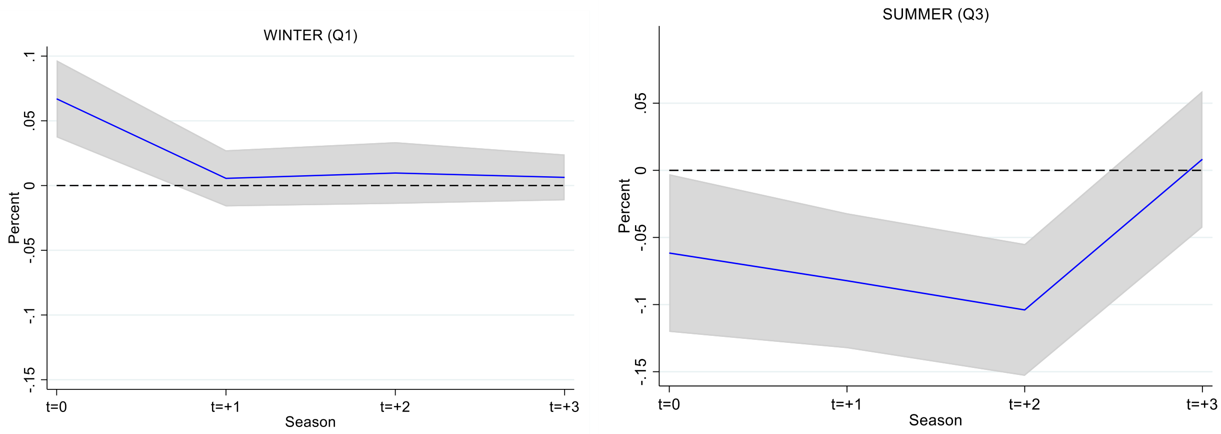
Controlling for Natural Disasters

This robustness controls for FEMA-declared natural disasters. We obtained the FEMA-declared disasters from FEMA website[9] at the county level. They include fire, severe storms, hurricanes, snowstorms, floods, tornados, severe ice storms, droughts, and volcanic eruptions. They might or might not be correlated with temperature. For example, a hotter temperature may lead to fire. I assign a dummy variable of 1 if a county experienced at least one FEMA-declared natural disaster in a quarter.

Figure 11 presents the dynamic impacts of temperature on employment growth after the natural disaster dummy variable is controlled for. Again, the impacts remain robust and similar to the baseline findings in Figure 1.

[99] https://www.fema.gov/openfema-data-page/disaster-declarations-summaries-v2

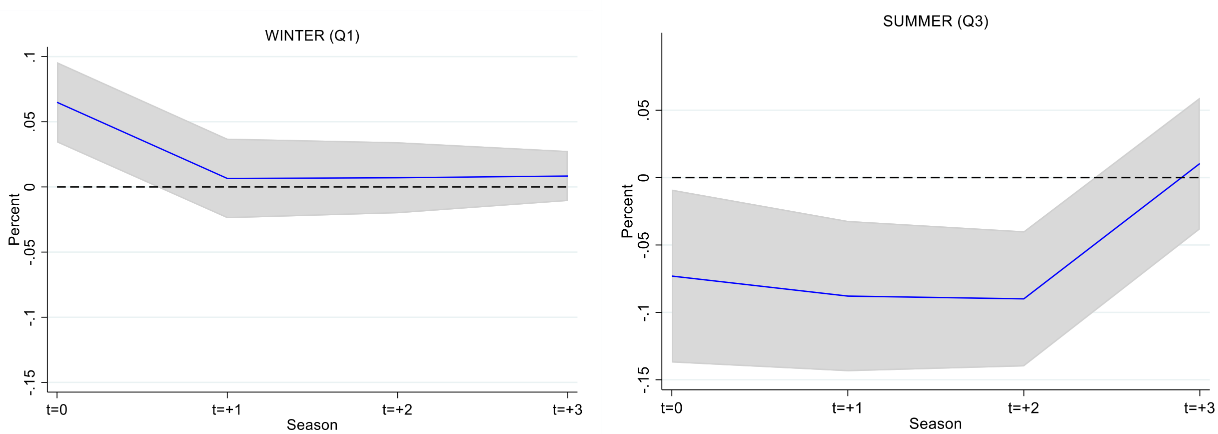
Figure 11: Dynamic Impact on YoY Employment Growth to a One Degree Fahrenheit Higher Temperature (Controlling for Natural Disasters)



Controlling for Precipitation

This robustness check controls for average daily precipitation at the county level. I collect precipitation data from the same sources of temperature (see Section III- Data). Existing literature, mostly on the annual frequency, shows that precipitation does not alter the effects of temperature on economic activity. Therefore, in this robustness check, I follow the baseline specification in equation (10) but also control for the average daily precipitation of the current quarter and the previous 7 quarters. The finding is very similar to the baseline finding. Figure 12 presents the dynamic impacts of temperature on employment growth after precipitation is controlled for. Again, the impacts remain similar to the baseline findings in Figure 1.

Figure 12: Dynamic Impact on YoY Employment Growth to a One Degree Fahrenheit Higher Temperature (Controlling for Precipitation)



X. Conclusions

Using temperature and employment data between 1990 until end of 2021, this paper examines the high-frequency dynamic impact of temperature at a local geographical level, namely US county. It finds that the effects are nuanced: hotter temperature in the summer hurts employment growth, while hotter temperature in the winter helps. However, the effects in the summer are larger and more persistent, hurting employment growth in subsequent quarters. In addition, the effects of a hotter summer have been more negative in recent decades and more negative in hotter states.

The findings suggest that colder regions or countries may benefit from climate change while hotter ones may be hurt without significant adaptation efforts. This finding presents a challenge for a unified effort to fight climate change. In addition, as the effects of a hotter summer have been more negative in recent decades, this implies adaptation efforts in the US have not taken hold or have not significantly altered the effects of a hotter summer. This finding has implications for other countries. Even for the US, a developed country with good adaptation capacity and generally mild climate, we observe negative impacts of higher temperature in the summer. For poorer, hotter countries, the effects of rising heat, without substantial adaptation efforts, are likely much more severe.

This paper highlights the need to study the impact of climate change at granular levels, in both time and space dimensions, to uncover the highly heterogenous effects of climate change.

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