Disentangling Drivers of Rangeland Degradation: Herd Size versus Climate in Mongolia, 1985-2022

Seminar at University of Bologna

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A Global Problem

- Rangelands are the most dominant land type on Earth and support the livelihoods of roughly two billion people (Briske, 2017a)
  - All rangeland-dependent economies face similar challenges in managing and sustaining these ecosystems (Le et al. 2014)
  - One of the biggest challenges is rangeland degradation, which adversely affects both environmental outcomes (e.g., biodiversity) and future livestock productivity (Nkonya et al. 2016)
  - Common rangeland degradation drivers are herd size, climate, fire, etc.

The Case of Mongolia: Rangeland Degradation

- The rangelands in Mongolia are widely perceived to have degraded rapidly over the last two decades
    - 45% of rural population depends on rangelands, up to 57% of which has degraded since 1990 revolution. (Densambuu et al. 2018)
    - Makes herders vulnerable to extreme weather events such as *Zud* ⏩ Show figure
    - Timing corresponds with a sharp increase in livestock herds after transition from central planning ⏩ Show trend
    - Also corresponds w/ significant change in climate (increase in annual average temperature and decrease in precipitation) ⏩ Show trend
    - In response to perceived degradation and herd size growth, gov't introduced a livestock tax. (Parliament of Mongolia, 2020)

Study Objective

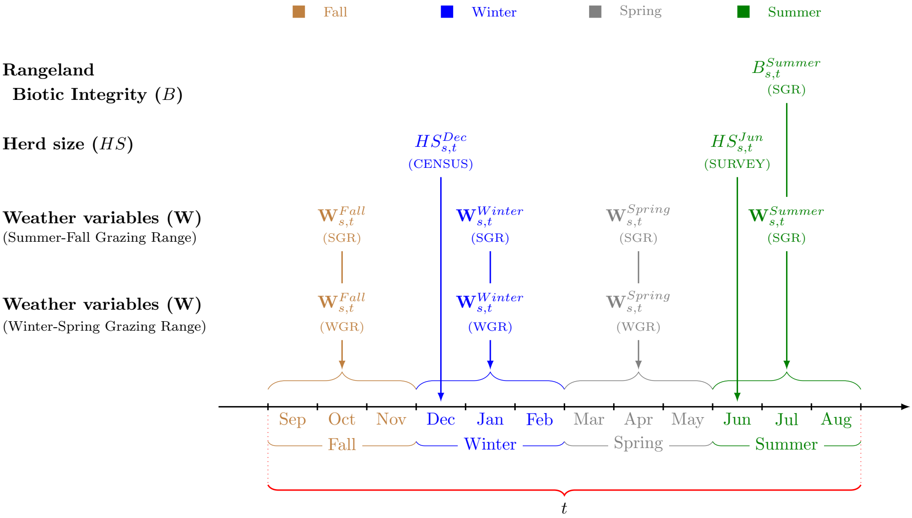
- Credibly distinguishing climate change from herd stocking rates as causal drivers of rangeland conditions
  - Taking into account endogeneity of herd sizes
  - Taking into account unobserved spatial and intertemporal variation from other sources that might be spuriously correlated with herd sizes and/or weather realizations

Data

- We are interested in *soum*-level variation in **rangeland process, herd size,and seasonal weather**:
  - 339 soums nationwide
  - A soum is unlikely to be comprised entirely of rangelands, so mask out non-grazing areas. Summer/fall and winter/spring grazing ranges are spatially distinct. Zuds strike WGRs. Show figure

Variables and Timeline

⏩ Show Summary ⏩ DAG



Empirical Strategy

Two-step estimator

- Goal: estimate the marginal effect of herd size and climate change on summer grazing range conditions.
- IV design, with a twist. Only have June herd sizes 2016-22 and zuds often occur after December herd census (available 1970-2022). Therefore, use small area estimation to estimate June herd size from instruments: zud measures and December census herd size ($\widehat{HS}_{st}^{Jun}$). Then project first stage from 2016-22 back to 1985 to generate instrumented June herd size. ▸▸ Show IV

$$\ln HS_{st}^{Jun} = \rho_1 \ln B_{s,t-1,SGR}^{Summer} + \alpha_1 \ln HS_{st}^{Dec} + \boldsymbol{W}_{s,t,SGR}^{Season}\boldsymbol{\beta}_1 + \boldsymbol{W}_{s,t,WGR}^{Season}\boldsymbol{\gamma}_1 + \nu_t + \mu_s + \epsilon_{st},$$

- In the second step equation, we use predicted June herd size from the first step along with seasonal weather exposure measures:

$$\ln B_{s,t,SGR}^{Summer} = \rho \ln B_{s,t-1,SGR}^{Summer} + \alpha \ln \widehat{HS}_{st}^{Jun} + \boldsymbol{W}_{s,t,SGR}^{Summer}\boldsymbol{\beta} + \boldsymbol{W}_{s,t,SGR}^{Other\ Seasons}\boldsymbol{\gamma} + \delta_t + \sigma_s + \varepsilon_{st},$$

First stage

Show summary | Show figure

	(a) Dependent variable: ln HS_{st}^{June}			
	(1)	(2)	(3)	(4)
ln $HS_{st}^{December}$	0.733***	0.722***	0.725***	0.728***
	(0.085)	(0.087)	(0.088)	(0.089)
ln $B_{s,t-1,SGR}^{summer}$	0.065***	0.064***	0.064***	0.059***
	(0.011)	(0.011)	(0.011)	(0.011)
Summer, t-1, WGR				
Rainfall (m, acc.)	0.587***	0.556***	0.578***	0.531***
	(0.055)	(0.057)	(0.058)	(0.063)
$GDD(>20)$	−0.001	−0.002**	−0.002**	−0.003**
	(0.001)	(0.001)	(0.001)	(0.001)
Fall, WGR				
Rainfall (m, acc.)	−0.499***	−0.444***	−0.440***	0.675
	(0.149)	(0.156)	(0.156)	(0.616)
$WD(>5)$	−0.006***	−0.007***	−0.007***	−0.004*
	(0.002)	(0.002)	(0.002)	(0.002)
Winter, WGR				
SD, kg/m^3	−0.005***	−0.005***	−0.005***	−0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
$FDD(<-20)$	−0.002***	−0.002***	−0.002***	−0.002***
	(0.001)	(0.001)	(0.001)	(0.000)
Spring, WGR				
$WD(>5)$	−0.007***	−0.008***	−0.007***	−0.007***
	(0.001)	(0.002)	(0.002)	(0.002)
Soum FE	Yes	Yes	Yes	Yes
Eco.-Year FE	Yes	Yes	Yes	Yes
Spring, Winter, Fall, SGR	NNN	YNN	YYN	YYY
R^2	0.98	0.97	0.98	0.98
N	2317	2314	2314	2314
F-test on IVs	47.19	37.78	37.87	25.58

Note: Significance: $*p < 0.10$, $**p < 0.05$, and $***p < 0.01$.

Second stage ⏩ Show summary

	(a) Dependent variable: $\ln B^{summer}_{st,SGR}$				
	(1)	(2)	(3)	(4)	(5)
$\ln \widehat{HS}^{June}_{st}$	−0.045***	−0.052***	−0.062***	−0.060***	−0.050***
	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)
Summer, SGR					
$GDD(10,15]$		−0.006***	−0.004**	−0.004***	−0.004**
		(0.002)	(0.002)	(0.002)	(0.002)
$GDD(15,20]$		−0.012***	−0.010***	−0.010***	−0.009***
		(0.002)	(0.002)	(0.002)	(0.002)
$GDD(>20)$		−0.018***	−0.015***	−0.015***	−0.012***
		(0.002)	(0.002)	(0.002)	(0.002)
Precipitation (m, acc.)		0.168	0.246**	0.245**	0.345***
		(0.106)	(0.106)	(0.106)	(0.107)
Wind speed (m/s, ave.)		−0.229***	−0.203***	−0.201***	−0.198***
		(0.029)	(0.030)	(0.030)	(0.030)
Soum, Eco.-Year FEs	Yes	Yes	Yes	Yes	Yes
Spring, Winter, Fall, SGR	NNN	NNN	YNN	YYN	YYY
N	10660	10654	10654	10654	10654
R^2	0.84	0.85	0.85	0.85	0.85

Note: Significance: $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

Climatic variation impacts rangeland productivity more than herd size.

	(a) Dependent variable: ln $B^{summer}_{st,SGR}$				
	(1)	(2)	(3)	(4)	(5)
Shapley $\%R^2$					
Herdsize	5.59	4.07	4.63	4.58	4.47
Climate	.	28.98	33.19	33.85	36.49
FEs	94.41	66.95	62.18	61.57	59.04

- Year and soum fixed effects, account for nearly 59% of the observed variation in rangelands NDVI.
- An additional 36% of is explained by observed variation in summer weather over the full period (i.e., climate pattern).
- Only 4% of the observed variation in rangelands is explained by observed changes in herd size and/or herd density.

Spatial Spillover Effects?

Same qualitative results when we use herd density allowing for inter-soum spillovers.

- On average, for each 1% increase in herd density, reflectance-based greenness declines by 0.07%, almost double the point estimate of the original herd size but still small compared to weather effects.
- The signs and magnitude of summer climate variable stay consistent

Show table

Ecosystem Heterogeneity Effects

Marginal effects may differ by ecological zones

- In mountain taiga, forest steppe, and steppe zones herd size has a negative significant effect omn NDVI at the 1% level
- Temperatures above 20°C have a negative significant impact on NDVI in forest steppe, steppe, semi desert, and desert zones but not in the mountain taiga zone Show table

Conclusions

- Livestock herds and climate both have had statistically significant, negative impacts on rangeland biological productivity.
- The relative contribution from climatic variation to rangeland degradation appears far greater
- Adverse herd size (temperature) effects are greatest (insignificant) in the mountain taiga zone
- Temperature (herd size) effects are largest (insignificant) in the semi-desert/desert zones.

Policy Implications

- Policies focused on herd size alone may have a limited effect on desired rangeland outcomes.
- Must consider variable impacts by ecological zone
- Local adverse impacts of global phenomena not caused by Mongolian herders appear to dominate.

Thank You!

Thank you for your interest, questions and comments.

Send further comments to cbb2@cornell.edu

Definition

Zud is a phenomenon when animals are lost en masse due to a lack of fodder during severe cold weather conditions in the fall, winter, or spring. ◂ Return

Livestocks dynamics in Mongolia

Return

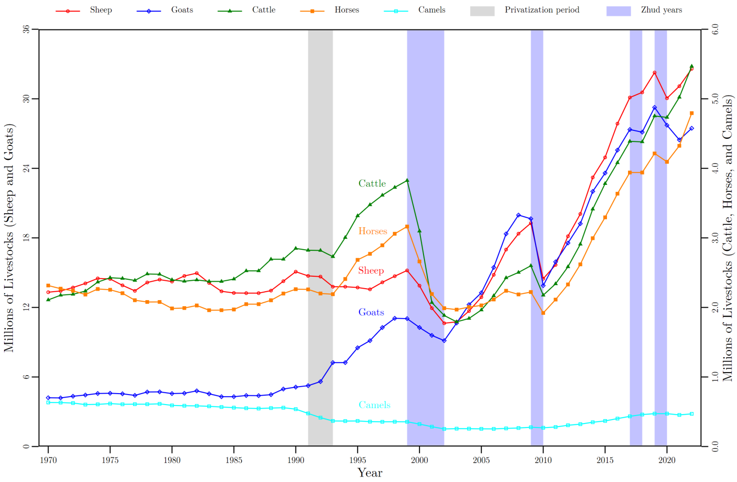


Figure: Livestock population dynamics in Mongolia from 1970 to 2022 (author's calculations using Mongolia's December livestock census data). The grey vertical line marks the beginning of privatization. The blue vertical lines mark the major Zud years, as reported by the government.

Aggregate changes in weather patterns

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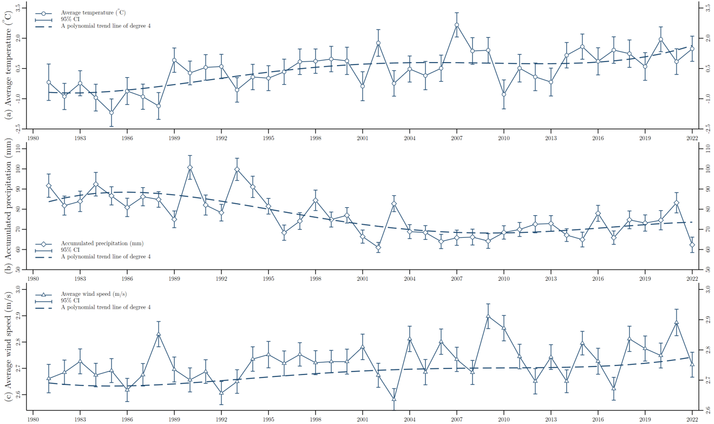

Figure: Time series plots of average temperature (Panel A), average accumulated precipitation (Panel B), and average wind speed (Panel C) (Author's calculations using ERA5-Land), with 95% confidence intervals and polynomial trend line (degree=4).

Seasonal Grazing Range

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at soum (district) level: 339 soums

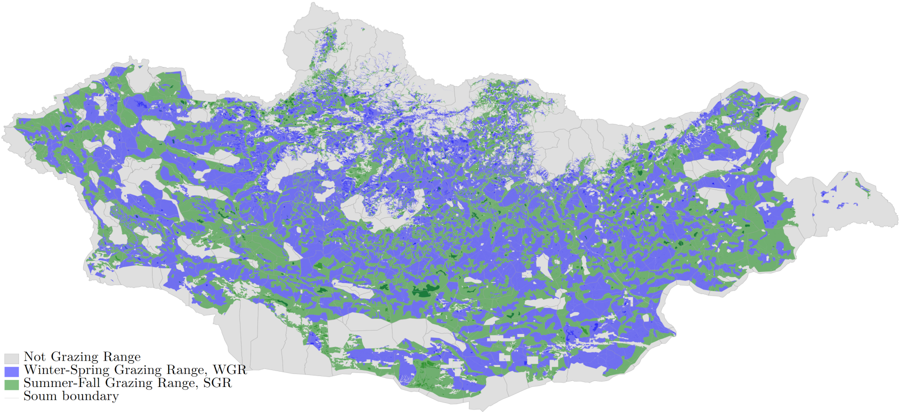

Figure: Winter grazing range areas (WGR) include areas used in winter and spring. Summer grazing range areas (SGR) include areas used in summer and fall. Gray areas are either not suitable for livestock or national protected areas.

Constructed Measures

Return

Rangeland quality (soum-level, summer grazing range)

- NDVI, 1985-2022, $B_{st,SGR}^{summer}$
- Ground-based vegetation biomass, 2001-2022

Weather (seasonal, soum-level, summer/winter grazing range, 1985-2022)

- Growing degree days, $GDD(\cdot)_{st,SGR}^{season}$, $GDD(\cdot)_{st,WGR}^{season}$
- Freezing degree days, $FDD(\cdot)_{st,SGR}^{season}$, $FDD(\cdot)_{st,WGR}^{season}$
- Windy days, $WD(\cdot)_{st,SGR}^{season}$, $WD(\cdot)_{st,WGR}^{season}$
- Precipitation (m), $TP_{st,SGR}^{season}$, $TP_{st,WGR}^{season}$
- Snow Density (kg/m^3), $SD_{st,WGR}^{season}$

Livestock (annual, soum-level)

- Herd size based on census (December), 1970-2022, HS_{st}^{Jun}
- Herd size based on survey (June), 2016-2022, HS_{st}^{Dec}

DAG

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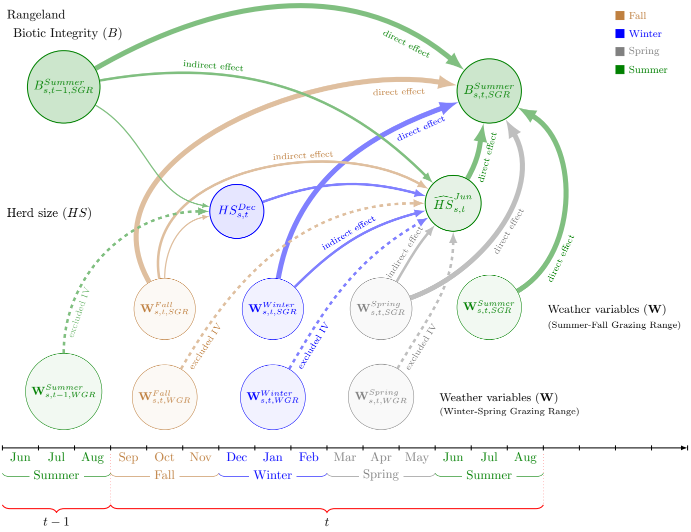


Rangeland
Biotic Integrity (B)
Herd size (HS)
$B^{Summer}_{s,t-1,SGR}$
$B^{Summer}_{s,t,SGR}$
$HS^{Dec}_{s,t}$
$\widehat{HS}^{Jun}_{s,t}$
$\mathbf{W}^{Fall}_{s,t,SGR}$
$\mathbf{W}^{Winter}_{s,t,SGR}$
$\mathbf{W}^{Spring}_{s,t,SGR}$
$\mathbf{W}^{Summer}_{s,t,SGR}$
$\mathbf{W}^{Summer}_{s,t-1,WGR}$
$\mathbf{W}^{Fall}_{s,t,WGR}$
$\mathbf{W}^{Winter}_{s,t,WGR}$
$\mathbf{W}^{Spring}_{s,t,WGR}$
direct effect
indirect effect
excluded IV
Fall
Winter
Spring
Summer
Weather variables ($\mathbf{W}$)
(Summer-Fall Grazing Range)
Weather variables ($\mathbf{W}$)
(Winter-Spring Grazing Range)
Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug
Summer Fall Winter Spring Summer
$t-1$
t

Validity of the IV, the harsh winter Return

We claim that *zud* or severe winter weather such as **snow density** and **exposure to temperature below - 20°C** is exogenous to herd size in June.

Relevance:

- Harsh winter conditions affect herd size. It induces variations in the number of livestock in each soum due to the degree of exposure.

Exogeneity:

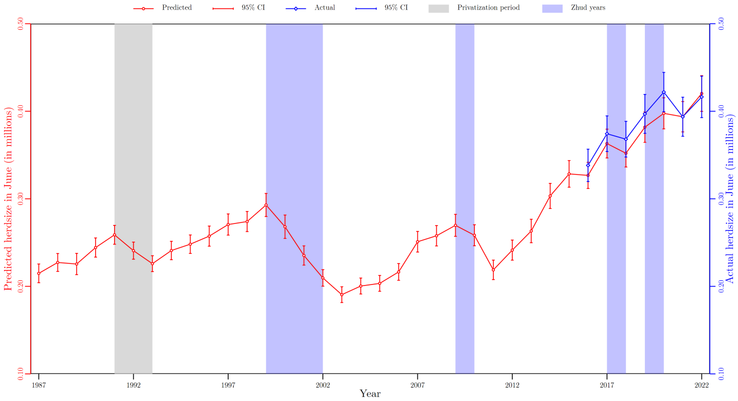
- Exogenously determined by the weather conditions

Exclusion:

- Conditional on weather in summer grazing ranges, the winter weather in the winter grazing ranges (which are spatially distinct from the SGRs) should only impact summer grazing land quality through its effects on herd size

Predicted soum-level herd size 1985-2022

Return



The predicted soum-level herd size 1985-2022 from the first step equation versus the observed herd size from the June livestock survey.

First Stage

◂ Show table

- The first-step results indicate our preferred instruments of Zud are negative (indicating that their occurrence decreases summer herd size) and statistically significant at the 1% level
- The December census exhibits a large, positive, and statistically significant effect on June herd size
- First stage F statistics on the excluded instruments are well above conventional threshold levels ranging, from 26-47

Second Stage

Show table

- Herd Size
  - On average, for each 1% increase in herd size, reflectance-based greenness (summer rangeland productivity) declines by 0.05%
- Summer Climate
  - The marginal effects of exposure to temperatures above 20°C is larger than the marginal effects at lower temperatures.
  - An additional 24 hours of exposure to temperatures above 20°C, reflectance-based greenness declines by around 1.2%. So one more hot day has a marginal effect comparable to a one-quarter increase in herd size.
  - Exposure to wind has a larger marginal effect indicating that for every 1 meter per second increase in average summer wind speed within SGRs, reflectance-based greenness declines by around 19%.
  - Cumulative average summer precipitation in SGRs has a large positive effect on greenness, indicating that for every 1 meter of average summer accumulated precipitation in SGRs, greenness increases by 39%

Spillover Effects

Return

	(a) Dependent variable: ln $B^{summer}_{st,SGR}$				
	(1)	(2)	(3)	(4)	(5)
ln $\widehat{HD}^{June}_{st}$	−0.056**	−0.078***	−0.097***	−0.093***	−0.074***
	(0.024)	(0.023)	(0.024)	(0.024)	(0.024)
ln $B^{summer}_{s,t-1,SGR}$	−0.001	−0.005	−0.003	−0.003	−0.003
	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)
Summer, SGR					
$GDD(10, 15]$		−0.006***	−0.005***	−0.005***	−0.004***
		(0.002)	(0.002)	(0.002)	(0.002)
$GDD(15, 20]$		−0.013***	−0.010***	−0.011***	−0.009***
		(0.002)	(0.002)	(0.002)	(0.002)
$GDD(> 20)$		−0.018***	−0.015***	−0.016***	−0.012***
		(0.002)	(0.002)	(0.002)	(0.002)
Precipitation (m, acc.)		0.156	0.237**	0.236**	0.341***
		(0.104)	(0.105)	(0.105)	(0.107)
Wind speed (m/s, ave.)		−0.229***	−0.201***	−0.200***	−0.197***
		(0.028)	(0.030)	(0.030)	(0.030)
Soum, Eco.-Year FEs	Yes	Yes	Yes	Yes	Yes
Spring, Winter, Fall, SGR	NNN	NNN	YNN	YYN	YYY
N	10901	10875	10875	10875	10875
R^2	0.84	0.85	0.85	0.85	0.85
Shapley $\%R^2$					
Herdsize	5.44	4.37	4.90	4.88	4.81
Climate	.	20.46	23.77	24.26	26.23
FEs	57.84	46.71	44.24	43.91	42.69
Lags	36.73	28.47	27.09	26.95	26.27

Note: Significance: $*p < 0.10$, $**p < 0.05$, and $***p < 0.01$.

Heterogeneity Effects

Return

	(a) Dependent variable: $\ln B^{summer}_{st,SGR}$				
	(1)	(2)	(3)	(4)	(5)
$\ln \widehat{HS}^{June}_{st} \times$ *Eco. zones*					
Mountain taiga	−0.052	−0.140***	−0.162***	−0.148***	−0.154***
	(0.039)	(0.032)	(0.031)	(0.031)	(0.033)
Forest steppe	−0.111***	−0.152***	−0.151***	−0.148***	−0.146***
	(0.019)	(0.020)	(0.019)	(0.019)	(0.019)
Steppe	−0.042**	−0.057***	−0.064***	−0.059***	−0.046**
	(0.020)	(0.021)	(0.021)	(0.021)	(0.023)
Semi desert	−0.045**	−0.030	−0.043*	−0.045*	−0.021
	(0.022)	(0.023)	(0.023)	(0.023)	(0.022)
Desert	0.024	−0.003	−0.019	−0.017	0.008
	(0.019)	(0.020)	(0.020)	(0.020)	(0.019)
$GDD(>20) \times$ *Eco. zones*					
Mountain taiga		−0.008	−0.006	−0.006	−0.002
		(0.005)	(0.004)	(0.005)	(0.005)
Forest steppe		−0.014***	−0.012***	−0.012***	−0.009***
		(0.002)	(0.002)	(0.002)	(0.002)
Steppe		−0.019***	−0.018***	−0.018***	−0.014***
		(0.002)	(0.001)	(0.001)	(0.001)
Semi desert		−0.019***	−0.018***	−0.018***	−0.014***
		(0.002)	(0.002)	(0.002)	(0.002)
Desert		−0.015***	−0.013***	−0.014***	−0.010***
		(0.002)	(0.002)	(0.002)	(0.002)
Year, Soum FEs	Yes	Yes	Yes	Yes	Yes
Other summer weather, SGR	No	Yes	Yes	Yes	Yes
Spring, Winter, Fall, SGR	NNN	NNN	YNN	YYN	YYY
R^2	0.83	0.84	0.85	0.85	0.85
N	10660	10654	10654	10654	10654

Note: Significance: $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.