EC1340 Topic #6

Climate damage III: The Little Ice Age

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Outline

The ‘Little Ice Age’ was a period of cold from about the late 1500’s until about the early 1700’s. This is exactly the variation in climate that we need to study the effects of climate change. We look at four studies that do exactly this.

1. Zhang et al. PNAS 2007
2. Oster, JEP 2004
3. Turner, AERPP 2012
4. Waldinger CEP 2015

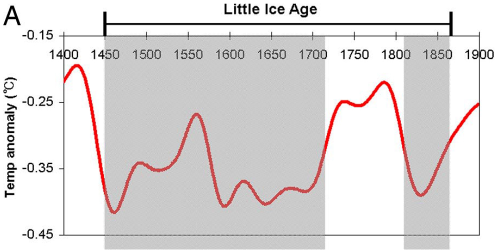
These studies use exactly the right variation, but do so in a much less developed world, and consider cooling not warming.

Zhang et al. PNAS 2007

Global climate change, war and population decline in recent human history

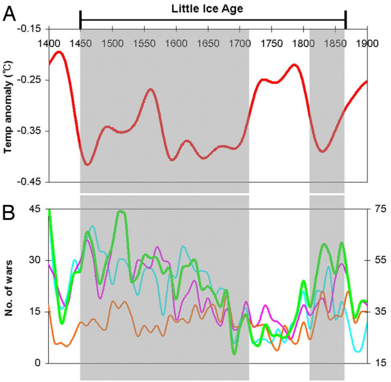
- This paper assembles long time series of data describing temperature, population, and conflict, and plots them next to each other.
- The paper really boils down to a series of figures.
- N.B.: This is a paper by anthropologists, and so it reads a little bit differently than an economics paper.

Temperature anomaly



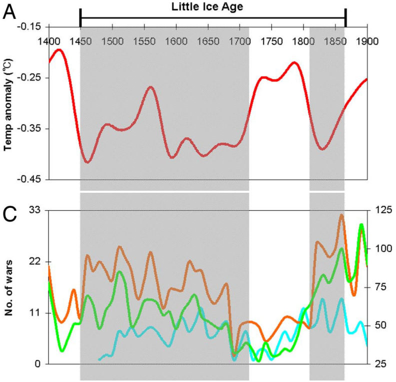
- This is mean Northern Hemisphere (NH) temperature that has been put through a ‘filter’(i.e., moving average) to smooth it out.
- There is a clear cold period from about 1450 to 1720. Dates move around a little with different data sources.
- This was the pre-industrial period when urbanization rates in Europe increased slowly (from about 10%-12%) and productivity increased slowly (until about 1750).

Temperature anomaly vs conflict #1



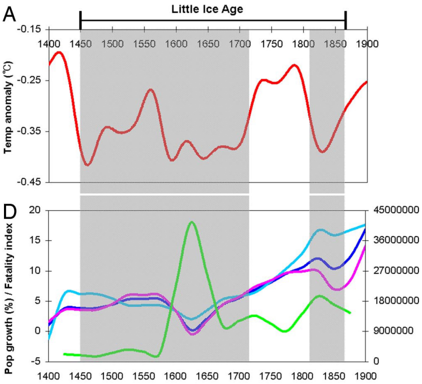
- Total NH wars (Green), Asia (Pink), Europe (Turquoise), Arid areas (Orange).
- More war in cold times, less in warm times. What is the mechanism?
- Why not make temperature series to match war series, e.g. European temperature?

Temperature anomaly vs conflict #2



- Total NH wars (Green), Asia (Pink), Europe (Turquoise), Arid areas (Orange).
- Different data source.
- Same pattern. More wars in cold times, less in warm times.
- Should this increase our confidence? (think measurement error).

Temperature anomaly vs population



- Pop Growth % Europe (Turquoise), Pink (Asia), NH (blue). NH 50 year fatality index.
- There is no obvious pattern here. What does this suggest about the mechanism behind the conflict result?

Conclusion, Zhang et al., PNAS 2007

- Suggestive evidence for a relationship between temperature and conflict.
- That temperature is not always defined over same geography as conflict is suspicious.
- There were other trends going on in the world during this time, too, e.g., economic growth, urbanization, the Colombian exchange.
- The data does not show the same pattern between climate and population growth. What would it show for population level? This makes the mechanism behind the conflicts unclear.

Oster, JEP 2004

Witchcraft, Weather and Economic Growth in Renaissance Europe

- Compare frequency of witch trials over the course of the little ice age in Europe.
- Why is this interesting? (1) Witch trials are bad and we want fewer of them. (2) We think witch trials are reflection of economic hardship.
- Issues: Same as Zhang et al. Is medieval European cooling informative about the costs of modern warming? There are other trends during this time.
- Also, it would be nice to know the relationship between witch trials and hardship a little more precisely.

Data

- Oster's data records witch trials in 11 European regions: Basel, Essex, Estonia, Finland, Eastern France, Geneva, England, Hungary.
- Data is by decade from 1520–1770. So, $k = 11, t = 1520 - 1770$. Some are missing, so $N = 170$ not $11 \times 25 = 275$.
- $k \sim$ regions, $t \sim$ decades.
- Let W_{kt} be # trials in region k decade t.

Measuring witch trials I

There are two econometric issues.

- Region specific propensity to try witches that may be correlated with mean climate.
- Some regions are much bigger than others and so tend to dominate regression results.

Response

- 'de-mean' the data. This is *almost* equivalent using a region fixed effect.
- normalize variance. This is almost equivalent to adding copies of small regions to the data set so they count have a bigger effect on the regression. This is called 're-weighting'. This will lead to trouble interpreting the results.
- Comment: non-standard solutions to these problems.

Measuring witch trials II

Let

$$\overline{W}_k = \frac{1}{25}\sum_{t=1}^{25} W_{kt}$$

$$SD(\overline{W}_k) = \left[\frac{1}{25}\sum_{t=1}^{25}(W_{kt} - \overline{W}_k)^2\right]^{\frac{1}{2}}$$

Define

$$W^*_{kt} = \frac{W_{kt} - \overline{W}_k}{SD(\overline{W}_k)}$$

This is the dependent variable measuring the incidence of witch trials.

Measuring witch trials III

W^*_{kt} has mean zero.

$$
\begin{aligned}
\frac{1}{25}\sum_{t=1}^{25} W^*_{kt} &= \frac{1}{25}\sum_{t=1}^{25}\frac{W_{kt}-\overline{W}_k}{SD(\overline{W}_k)} \\
&= \frac{1}{25SD(\overline{W}_k)}\sum_{t=1}^{25}\left[W_{kt}-\overline{W}_k\right] \\
&= \frac{1}{25SD(\overline{W}_k)}\left[\sum_{t=1}^{25}W_{kt}-25\overline{W}_k\right] \\
&= \frac{1}{25SD(\overline{W}_k)}25\left[\overline{W}_k-\overline{W}_k\right] \\
&= 0^*_k
\end{aligned}
$$

Measuring witch trials IV

W_k^* is ‘demeaned’.

Measuring witch trials V

W_k^* has standard deviation 1 for each k.

$$
\begin{aligned}
SD(W_{kt}^*) &= \left(\frac{1}{25} \sum_{t=1}^{25} (W_{kt}^* - \overline{W}_k^*)^2 \right)^{\frac{1}{2}} \\
&= \left(\frac{1}{25} \sum_{t=1}^{25} [W_{kt}^*]^2 \right)^{\frac{1}{2}} \\
&= \left(\frac{1}{25} \sum_{t=1}^{25} \left[\frac{W_{kt} - \overline{W}_k}{SD(\overline{W}_k)} \right]^2 \right)^{\frac{1}{2}} \\
&= \frac{1}{SD(W_{kt}^*)} \left(\frac{1}{25} \sum_{t=1}^{25} \left[W_{kt} - \overline{W}_k \right]^2 \right)^{\frac{1}{2}} \\
&= \frac{1}{SD(W_{kt}^*)} SD(W_{kt}^*) = 1
\end{aligned}
$$

Climate data

- This period predates the instrumental record.
- But, there is a record of things like; date of first frost, date of ice-free harbor, etc. that allow historians to reconstruct *regional* climates. NB: Icecores are global.
- This leads to decadal average measures of 'winter severity' by region.
- Denote this index of winter severity by T_{tk} (definition a little opaque).
- Calculate $T^*_{kt} = \frac{T_{kt} - \overline{T}_{kt}}{SD(T_{kt})}$. Also mean zero and SD of 1.

Trials vs. Temp I

We want to look at the relationship between T^*_{kt} and W^*_{kt}

- First,

$$W^*_{kt} = A_0 + A_1 t + A_2 t^2 + W^{**}_{kt}$$
$$T^*_{kt} = A_0 + A_1 t + A_2 t^2 + T^{**}_{kt}$$

- Why? These variables are now de-trended. We care about this if we think, e.g., there were fewer witch trials as technology improved slowly during the middle ages.

Trials vs. Temp II

- Finally,

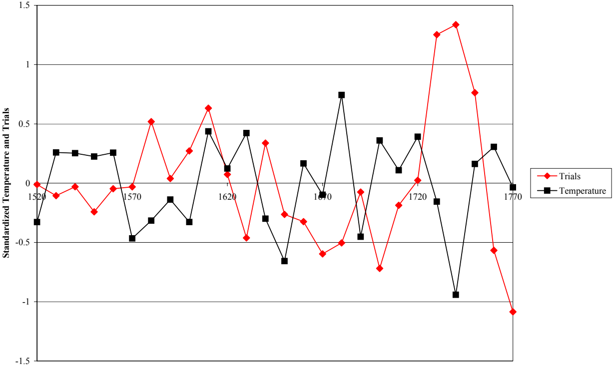
$$W_t^{***} = \frac{1}{11} \sum_{k=1}^{11} W_{kt}^{**}$$

$$T_t^{***} = \frac{1}{11} \sum_{k=1}^{11} T_{kt}^{**}$$

- These are mean (across regions) decadal deviations of temperature and trials from a quadratic trend, of the demeaned and normalized variables.
- They should not reflect region specific factors – they are demeaned.
- They should not reflect other trends in the data.

Plots of W_t^{***} and T_t^{***}

Figure 1: Temperature and Trials over Time
1520-1770



Trials are high when temperature is low.

Regressions

Estimating equations,

$$\overline{W}^*_{kt} = A_0 + A_1 t + A_2 t^2 + A_3 T^*_{kt} + \varepsilon_{kt}$$

and

$$\overline{W}^*_{kt} = A_t + A_3 T^*_{kt} + \varepsilon_{kt},$$

where A_t is 25 year fixed effects. That is, $\sum_{t=1}^{25} A_t \theta_t$ and θ_t is 1 in year t and 0 else.

Table 1[a]
Witchcraft Trials and Temperature
Dependent Variable: Witchcraft Trials Standardized by Region

	(1)	(2)	(3)	(4)
Standardized Combined Index	-0.212***		-0.206**	
	(2.59)		(2.32)	
Standardized Winter Severity Only		-0.179**		-0.292***
		(1.96)		(2.84)
Date	0.096	0.233***		
	(1.96)	(3.43)		
Date-Squared	-0.003	-0.011***		
	(1.43)	(3.45)		
Constant	-0.645**	-1.037***	-0.019	-0.059
	(2.39)	(3.16)	(0.26)	(0.71)
Decade Fixed Effects (1520-1770):	NO	NO	YES	YES
Observations	170	128	170	128
R-squared	0.10	0.15	0.24	0.28

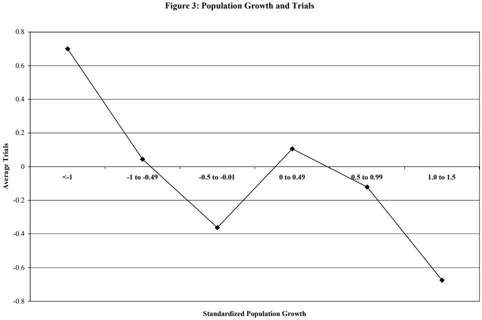
Absolute value of t-statistics in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

- There is a pretty clear negative relationship between trials and temperature, condition of t.
- ... but b/c the variables have been transformed so many times it is hard to know the effect of, e.g, 1°of cooling.

Urban share vs Trials

- When the economy is most agricultural, if ag. productivity increases, so does urban population.
- Urban population is a measure of economic productivity.
- Use urban share and count of cities$>$ 10,000 to measure urban population.
- Data is available every 50 years.
- Calculate Population growth rates (%) and % growth in big cities.
- This gives growth rates for 5 periods and 11 regions. Aggregate trial data to 50 year periods, to match.

Trials vs population growth



- There are fewer trials when there is more population growth.
- ... witch trials actually tell us something about the whole state of the economy.

Summary

Long term climate change, cooling, pretty clearly had harmful effects. This is exactly the right sort of variation that we want to understand these effects, but...

- Warming not cooling.
- Pre-industrial Europe, not modern world.
- Funny outcome variable.
- Transformed temperature index is hard to relate to the RCPs we think about now.
- Can we compare these data to Zhang et al? Nope. They have been demeaned and detrended.

Population, adaption and climate in Iceland I

- Look at relationship between climate and population size in pre-industrial Iceland, 1720-1840.
- How do people adapt to climate change ? Is a cold shock worse if it follows a cold period or a warm period?

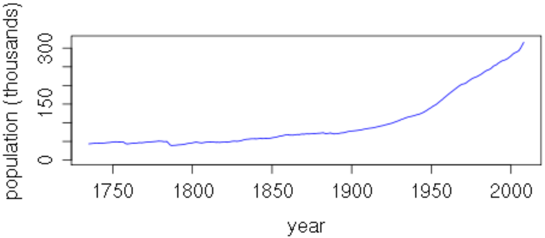
Background, 1720-1840, Iceland was

- Very poor. People mostly lived by raising sheep. There was a little fishing.
- Very little migration in or out. This was a policy of the Island's feudal rulers who wanted stability.
- Little technological progress – unusually so – again, this was a policy choice by feudal rulers who wanted stability.

So,

Population, adaption and climate in Iceland II

- Because so little else changed, if we see a relationship between population and climate, we can be pretty sure it's causal. We don't need to worry about climate shocks being mitigated by technological progress or migration.
- Because Iceland is poor, expect big effects.
- Finally, there is a long series of annual population data for Iceland, constructed from Church records. This is unusual.



Population was pretty stable until well into the industrial revolution.
Study the period before 1860.

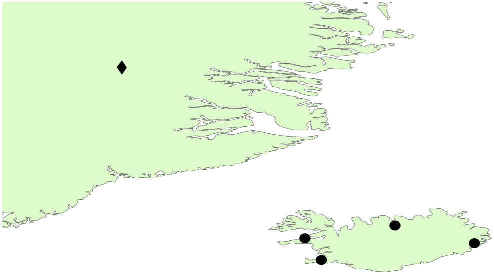
Climate data

- Between about 1920 and 1970, icecore and measured temperature records overlap.
- We use an icecore taken from nearby Greenland glaciers (see figures) and use them to impute a long time series of temperature.

$$Temp_t = A_0 + A_t Icecore_t + \varepsilon_t, \; t = 1910 - 1970$$
$$\widehat{Temp}_t = \widehat{A}_0 + \widehat{A}_1 Icecore_t, \; t = 1720 - 1860$$

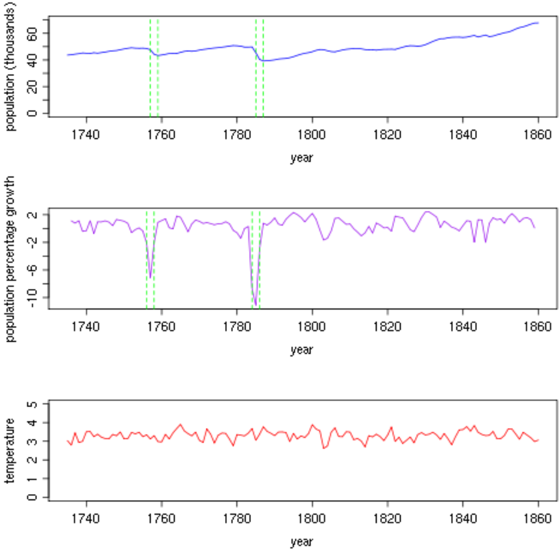
- This leaves us with a long series of both population and imputed temperature.

Icecore locations



Diamond is icecore, circles are weather stations.

Turner, AERPP 2012



Green is famines.

Population vs. temperature I

Define,

$$\triangle Pop_t = \frac{Pop_{t+1} - Pop_t}{Pop_t} \times 100$$
$$= \text{\% change in pop}$$

Now define ‘lagged moving averages’,

$$MA2_t = \frac{1}{2}(Temp_t + Temp_{t-1}), \text{ or}$$
$$MAj_{t-1} = \frac{1}{j}(Temp_{t-i} + Temp_{t-i-1} + ... + Temp_{t-i-j})$$

We are interested in three types of regressions.

Population vs. temperature II

- ΔPop on short run climate. How important is recent climate? How many people starve in a cold year?
- ΔPop on long run climate (10-20 year average temp). How important is longer run climate? After many hard years, how much does the population shrink?
- ΔPop on long run $\times$ short run climate. Does the response to the shock depend on history? How much do people adapt to cold?

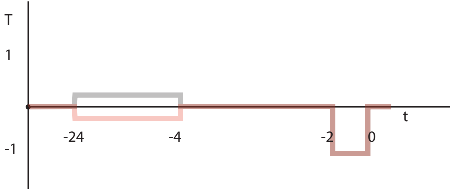
TABLE 1—NINE REGRESSIONS (ONE PER COLUMN) PREDICTING $(\Delta pop)_t$.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MA2_t	1.143***					1.153***	1.133***	1.084***	1.104***
	(0.359)					(0.355)	(0.353)	(0.323)	(0.298)
MA5_t		0.582							
		(0.721)							
MA10_t			1.172						
			(0.971)						
MA10_{t-4}				0.364		0.485		0.710	
				(1.051)		(1.017)		(1.044)	
MA20_{t-4}					-0.897		-0.208		-0.005
					(1.590)		(1.572)		(1.544)
$\text{MA2}_t \times \text{MA10}_{t-4}$								7.690*	
								(4.454)	
$\text{MA2}_t \times \text{MA20}_{t-4}$									11.10*
									(5.960)
pop_t	-0.089***	-0.091***	-0.086***	-0.090***	-0.093***	-0.087***	-0.089***	-0.092***	-0.093***
	(0.027)	(0.025)	(0.026)	(0.025)	(0.026)	(0.026)	(0.027)	(0.026)	(0.028)

Control variables in all regressions are: $time$, $time^2$, $(\Delta pop)_t$ and a constant.
Newey-West standard errors in parentheses. p-values: *** p<0.01, ** p<0.05, * p<0.1.

Columns 1-7 are regressions of ΔPop on recent on long run climate. Columns 8-9 involve interactions and are a little harder to understand.

Turner, AERPP 2012



- Consider two temperature histories, pink and grey.
- Grey: $MA2_t = -1$ and $MA20_{t-4} = 1/10$
- Pink: $MA2_t = -1$ and $MA20_{t-4} = -1/10$
- From Col 9,

$$\begin{aligned}\Delta Pop_t &= 1.104MA2_t + (-0.005)MA20_{t-4} \\ &+ 11.1(MA2_t \times MA20_{t-4}) \\ \Longrightarrow &\Delta Pop_t \approx -2.2, \text{ grey} \\ \Longrightarrow &\Delta Pop_t \approx 0, \text{ pink}\end{aligned}$$

- Two cold winters following 20 years of warm causes a 2% decrease in population. Two cold winters following 20 years of cold has almost no effect.
- Icelanders ‘adapt’ to colder climate over about a generation.

Issues:

- Non-linearities mean the magnitude of the adaption process is sensitive to magnitudes.
- Be suspicious. Data quality is poor.
- Lagged population should affect current population directly. This would need a model.
- How relevant is pre-industrial Iceland to anything?
- If we can really adapt to a new climate in a generation, that seems pretty important. Some of the adaptations are ‘getting smaller’, and so are pretty costly.

Economic effects of long-term climate change

This is similar to the other little ice-age papers, but

- most of Europe
- sheds more light on mechanisms
- provides nice evidence of adaptation

Data I

- Population of 2191 European cities with Pop$>$5000 sometime between 800 and 1850, for 1600, 1700, 1750.
- Gridded annual temp from most of Europe for 50km^2. From many sources, much like Oster's data, but now available in a grid.
- Drop cities in Far Eastern Europe and with missing temp, $N = 2120$.
- Define temperature as

$$Temp_{it} = \begin{cases} \frac{1}{100}\sum_{\tau=1}^{100} Temperature_{it-\tau} & \text{for 1600 and 1700} \\ \frac{1}{50}\sum_{\tau=1}^{50} Temperature_{it-\tau} & \text{for 1750} \end{cases}$$

- main outcome measure is $\ln(citypop)$.
- Yield Ratio is also important. This is Harvest/Sewn. Annual data from 12 countries from about 1500 to about 1750.

Temperature in four cities

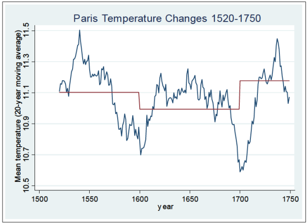


Figure 3: The graph plots yearly temperatures (20 years moving averages) for Paris and the corresponding computed long-term averages (straight lines).

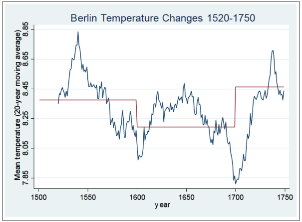


Figure 2: The graph plots yearly temperatures (20 years moving averages) for Berlin and the corresponding computed long-term averages (straight lines).

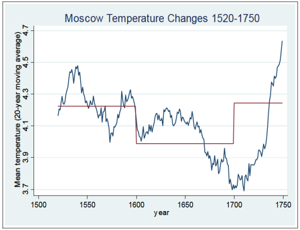


Figure 1: The graph plots yearly temperatures (20 years moving averages) for Moscow and the corresponding computed long-term averages (straight lines).

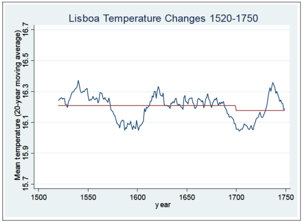


Figure 4: The graph plots yearly temperatures (20 years moving averages) for Lisbon and the corresponding computed long-term averages (straight lines).

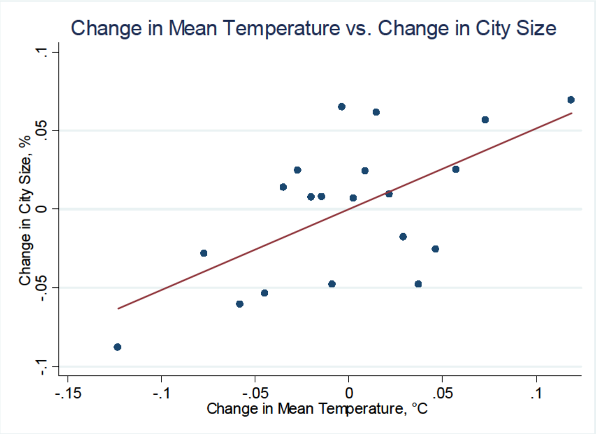


Figure 5: The figure displays a binned scatter plot corresponding to the estimates from column 6 of table 2. I residualize Log City Size and Mean Temperature with respect to city fixed effects, year fixed effects and geographic control variables using an OLS regression. I then divide the sample into 20 equally sized groups and plot the mean of the y-residuals against the mean of the x-residuals in each bin.

Cities

grow more slowly when it gets colder.

TABLE 1 - Summary Statistics			
	(1)	(2)	(3)
	All	**Above average fall in temperature**	**Below average fall in temperature**
City size in 1500	3.712	3.308	4.118
	9.962	*9.660*	*10.242*
Mean Temperature in 1500	10.601	8.284	12.927
	3.296	*1.725*	*2.824*
City Growth, 1500 to 1750	4.368	4.947	3.788
	19.439	*24.589*	*12.233*

Cities that got colder are smaller and grow more slowly.

TABLE 2 - The Effect of Temperature on City Size - Baseline Estimates and Geographic Controls

	Ln City Size					
	(1)	(2)	(3)	(4)	(5)	(6)
Mean Temperature	0.567***	0.653***	0.624***	0.565***	0.490***	0.491***
	(0.127)	(0.142)	(0.143)	(0.139)	(0.144)	(0.144)
City Fixed Effects	yes	yes	yes	yes	yes	yes
Year Fixed Effects	yes	yes	yes	yes	yes	yes
Geographic Controls (×Year Fixed Effects)						
ln Elevation		yes	yes	yes	yes	yes
ln Wheat Suitability			yes	yes	yes	yes
ln Potatoe Suitability				yes	yes	yes
ln Ruggedness					yes	yes
precipitation						yes
Observations	6,360	6,360	6,360	6,360	6,360	6,360
R-Squared	0.885	0.886	0.886	0.886	0.887	0.887

Robust standard errors in parentheses, clustered at city level
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: Observations are at the city-year level. All regressions use a baseline sample of 2120 cities. The time periods are 1600, 1700, and 1750. The dependent variable is the natural log of number of city inhabitants. Mean temperature is year temperature averaged over the periods 1500 to 1600, 1600 to 1700, and 1700 to 1750. The variables ln Wheat Suitability and ln Potato Suitability are the natural log of a wheat and potato suitability index defined by IIASA/FAO (2012). The measure for ruggedness is defined as in Nunn and Puga (2012). For more detailed information, please see the Data section.

- Estimating equation,

$$\ln(\text{City Pop})_{it} = \beta + \gamma Temp_{it} + a_t + l_i + x_{it} + \varepsilon_{it}$$

  Want γ. *a* is year fixed effects, *i* is city fixed effects, *x* is control variables.
- Cities that get colder, grow more slowly after controlling for fixed city characteristic related to cold and growth.

TABLE 9 - The effect of yearly temperature on yearly yield ratios

	Yield Ratios				
	(1)	(2)	(3)	(4)	(5)
Mean Temperature	0.430***	0.459***	0.451***	0.434**	0.543*
	(0.111)	(0.112)	(0.112)	(0.142)	(0.259)
Year Fixed Effects	yes	yes	yes	yes	yes
Country Fixed Effects	yes	yes	yes	yes	yes
Control Variables (×Year Fixed Effects)					
Precipitation		yes	yes	yes	yes
Battle			yes	yes	yes
Access to Ocean				yes	yes
Atlantic Trader					yes
Observations	702	702	702	702	702
R-Squared	0.802	0.803	0.803	0.820	0.847

Robust standard errors in parentheses, clustered at country level
*** p<0.01, ** p<0.05, * p<0.1

Note: Observations are at the country-year level. Data on yield ratios are taken from Slicher van Bath (1963) and available for locations in 12 European countries: Belgium, Czechoslovakia, Denmark, France, Germany, Great Britain, Italy, Netherlands, Poland, Russia, Spain, and Switzerland for various years starting in 1504.

- Country year regressions of Yield Ratio on $Temp_{it}$
- Note that coefficient in population regressions and yield regressions are about the same. Should we expect this? Hint: about 90% of population was rural/agricultural.

TABLE 11 - Exploring Economic Heterogeneity

	Ln City Size				
	(1)	(2)	(3)	(4)	(5)
Mean Temperature	0.487***	0.746***	0.691***	0.602***	0.984***
	(0.144)	(0.190)	(0.177)	(0.157)	(0.209)
Mean Temperature Interacted with:					
Big City		-0.601***			-0.486**
		(0.191)			(0.197)
Access to Waterways			-0.464**		-0.429**
			(0.209)		(0.209)
Hanseatic League				-0.568***	-0.495**
				(0.213)	(0.209)
City Fixed Effects	yes	yes	yes	yes	yes
Year Fixed Effects	yes	yes	yes	yes	yes
Geographical Controls (× Year Fixed Effects)	yes	yes	yes	yes	yes
Observations	6,360	6,360	6,360	6,360	6,360
R-Squared	0.887	0.887	0.887	0.887	0.887

Robust standard errors in parentheses, clustered at city level
*** p<0.01, ** p<0.05, * p<0.1

- Estimating equation,

$$\ln(\text{City Pop})_{it} = \beta + \gamma_0 \mathit{Temp}_{it}\beta + \gamma_1 \mathit{Temp}_{it} \times z_{it} + a_t + l_i + x_{it} + \varepsilon_{it}$$

- Cities with good access to inland trade experience almost no harm from cooling. Trade allows almost complete adaptation.
- This seems really important.

Conclusion I

- Climate change, colder, is bad,
  - Zhang et al, $\Longrightarrow$ conflict
  - Oster $\Longrightarrow$ witch trials
  - Turner et al., Waldinger $\Longrightarrow$ fewer people
- Turner: -1°C for 20 years $\Longrightarrow$ population falls by 9%. Compounding to get a 100 year effect, we have $(1 - 0.09)^5 = 0.62$, so after 100 years of cold, population is only 62% of original – not allowing for adaptation.
- Waldinger: -1°C for 100 years $\Longrightarrow$ city population shrinks by a factor of 0.61 ($e^{-0.5}$). Note close agreement between Waldinger and Turner et al.

Conclusion II

- In Iceland there were few opportunities for adaption. No migration. little trade, little progress. Adaption was probably costly, smaller bodies and living closer to domestic animals.
- Climate change was clearly stressful for humans, but these papers suggest that adaption was possible and pretty quick, even for pre-industrial societies.
- Issues,
  - Did trading cities benefit at the expense of their hinterlands?
  - Does medieval history tell us anything useful about the world today?
  - Beware, data quality is not great in any of these papers.