Sessions – 409 and 304

Fragile males on the American frontier: the role of environmental harshness and infrastructure development on sex ratios at birth before and after industrialization

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Abstract

While sex ratios at birth (SRB) have been shown to vary within and across populations, after over a century of research, understanding why has remained elusive. A variety of ecological, demographic, economic, and social variables have been evaluated, yet their association with SRB have been equivocal. Here, in an attempt to shed light on this unresolved topic within the literature, we approach the question of what drives variation in offspring sex ratios using detailed longitudinal data spanning the frontier-era to the early 20th century in a US population. Using several measures of environmental harshness, we find that fewer boys are born during challenging times. However, these results hold only for the frontier-era and not into the period of rapid industrialization. We argue that the mixed state of the literature may have to do with the fact that the impact and frequency of exogenous stressors are likely dampened in post-industrial societies.

Introduction

Exposure to prenatal stress is expected to decrease the ratio of male-to-female live births (sex ratio at birth; SRB; Catalano et al. 2006; Hansen, Moller and Olsen 1999). While sons do experience higher mortality rates across all stages of development, sources of maternal and/or environmental stress are anticipated to negatively impact male outcomes more so than female ones. This is argued to be due, in part, to the greater metabolic investments required by mothers to bring a son to term. Accordingly, this has earned them the moniker 'fragile males' in response to their predicted greater sensitivity than daughters to challenging ecological conditions.

While it is well-documented that SRBs vary within and across populations, understanding why, however, has been labeled as one of the most elusive concepts in the life sciences today (Pavic 2015). Central to the 'fragile male' approach is the assumption of greater male susceptibility to exogenous stressors - specifically that SRBs should decline during 'bad' times. While predictions from this framework are relatively straightforward, findings in the literature indicate no clear support for this approach. For example, during the Dutch Hunger Winter (1944-45), where mothers experienced severe resource deprivation over a period of seven months during WWII, SRBs were not significantly different from those in less stressful times (Stein, Zybert and Lumey 2004). However, other work analyzing data from over a three year famine in China during the Great Leap Forward (1959-61) finds a precipitous drop in male births in response to resource shortage (Song 2012; however see Zhao, Zhu and Reimondos 2013 for competing findings)

One explanation for the mixed state within the literature may have to do with the degree of economic development within a population. Both the impact and frequency of exogenous stressors are likely dampened in post-industrial societies (Scalone and Rettaroli 2015) due to medical advances and public health programs. Accordingly, infrastructure development, which allows access to cities and health care, may play a crucial role as to whether or not environmental stressors affect SRBs. In order to bring a degree of resolution to the literature, here we analyze a longitudinal dataset that varies across time in terms of infrastructure development and population-level exposure to exogenous stressors such as resource shortages.

Settlement and Economic Development of Utah

The settlement of what is now the state of Utah began in 1847. Initially, Salt Lake County served as a central settlement area, with smaller populations forming to the north and south (Bean Anderton Mineau 1990). Over the next twenty years, migration rates were high and the Euro-American population grew rapidly. During this frontier period, the economy was primarily an agrarian one, with most households maintaining a small farm holding. However, after the completion of the transcontinental railroad and the driving of the Golden Spike in 1869, industrialization rapidly began as urban populations began to grow, the manufacturing industry became established, and communities became connected through roads and rail systems allowing for the rapid movement of goods and people. Thus, 1869 serves as a useful benchmark as an end to the frontier-era in Utah and the beginning of an industrializing state economy.

During the frontier-era, farmers practiced a mix of dryland and irrigated farming, but in both cases crop productivity was heavily dependent on rainfall (Neff 1984). Severe droughts were documented during this time period and there is evidence that rates of mortality followed inter-annual variation in rainfall. Accordingly, here, to assess predictions from a ‘frail male’ approach, we look to historical indicators of the environment and their association with SRB. The Great Salt Lake (GSL) serves as a useful indicator of annual precipitation and thereby can be used as a gauge for ecological harshness over time.

Hypotheses

1. Hardship, as measured by GSL metrics, will be negatively associated with SRB because boys are less resilient to environmental harshness.
2. The effect of GSL metrics on SRBs will be strongest in Salt Lake County because of its proximity to the lake compared to other Utah counties.
3. The effect of GSL metrics on SRBs will be strongest historically and prior to the placing of the Golden Spike before industrialization began in Utah

Methods

Sample and Data

Data are derived from the Utah Population Database (UPDB), and a historical water report (Bowles et al. 1985). The UPDB is a premiere and unique genealogical database containing information on nearly nine million individuals. It includes genealogies and vital records of the founders of Utah from the 19th century to present time, as well as their descendants. It is annually updated with records of Utah birth and death certificates, driver licenses, and extensive medical and vital records. The database now includes over two million Utah birth certificates and in excess of 800,000 death certificates spanning almost a century. The Utah Resource for Genetic and Epidemiologic Research (RGE) administers access to these data. All research requires IRB human subjects and RGE approval (Wylie and Mineau 2003). The confidentiality of individuals represented in these records is maintained based on agreements between RGE and the data contributors. The report by Bowles et al. (1985) contains data and details of methodologies for four historical measures of GSL dynamics, from 1851 through 1983. The four variables of interest are GSL elevation, river inflow, precipitation, and evaporation.

By linking these datasets by year, we obtain the necessary data to evaluate our hypotheses. To be included in the final dataset, individuals had to have a known sex, year of birth, and county of birth in Utah (to determine geographic proximity to GSL). All individuals were required to be born between 1847 and 1919. The end point of 1919 was chosen because we did not wish to proceed too far into the modern era and, also, 1919 is the end of WWI, following which there were dramatic economic changes in Utah. The unit of analysis was a geographic-year, with one observation for each year and each geography (Salt Lake County and non-Salt Lake County). Thus, we had two observations for each year.

Variables

UPDB Variables

Secondary Sex Ratio was an interval-level variable determined as the number of male births divided by the number of female births. It was calculated for each year and each geography (Salt Lake County or Other County – see below).

Pre-spike was indicated by a dummy variable capturing the period before 1869 (1 for 1851-1869, 0 for 1870-1919).

Salt Lake County was measured with a dummy variable (1 for born in Salt Lake County, 0 for born in another county)

Great Salt Lake Measures

We employ four measures of potential hardship relevant to the GSL.

Annual Peak Lake Elevation in feet, hereafter referred to as simply *elevation*. Values estimated before 1876. Higher levels likely indicate a better environment.

River inflows in 1000 acre-feet, hereafter simply referred to as *river flow*. This includes the combined totals from Bear, Weber, and Jordan Rivers. Values estimated before 1890. Higher levels should indicate a better environment.

Lake Precipitation in inches, hereafter simply referred to as *inches*. Values estimated before 1875. Higher levels should indicate better environment.

Lake Freshwater Evaporation in inches, hereafter referred to simply as *evaporation.* Values estimated before 1937. Note this encompasses the entirety of our sample. Of the four GSL measures, this is the only one where higher levels should indicate worse environment.

Flags

A flag dummy variable for whether a GSL measure was estimated was included for elevation, river inflow, and precipitation measures as appropriate.

Analysis

Analyses were performed in SAS 9.4. First, we examined simple correlation coefficients to test for significant relationships between the four GSL measures and SRB. Second, a linear least square regression models were estimated for each GSL measurement. SRB was the outcome, and each of the three variables (the relevant GSL measure, Pre-Golden Spike, and SL County), three two-way interactions, and a three-way interaction were included in the models.

The equation to be estimated is:

$$srb = \beta_0 + \beta_1 r + \beta_2 t + \beta_3 g + \beta_4 r \times t + \beta_5 r \times g + \beta_6 t \times g + \beta_7 r \times t \times g + \beta_7 f$$

where *SRB* is the interval-level secondary sex ratio, *r* is the relevant GSL risk factor (i.e., elevation, river inflows, precipitation, or evaporation), *t (time)* is the Pre-golden Spike indicator, *g (i.e., geography)* is the Salt Lake County indicator, and *f* is a flag for whether the risk factor was estimated. The marginal effect of SRB with respect the GSL risk factor, then, is:

$$\frac{\partial srb}{\partial r} = \beta_1 + \beta_4 t + \beta_5 g + \beta_7 t \times g$$

Since *t* and *g* are simple 0/1 binary variables, from this we derive a two-by-two contingency table to examine the marginal effects separately by time and geography.

		Time (Pre-spike = 1)	
		0	1
Geography (Salt Lake County = 1)	0	β_1	$\beta_1 + \beta_4$
	1	$\beta_1 + \beta_5$	$\beta_1 + \beta_4 + \beta_5 + \beta_7$

Parameters were estimated with *PROC REG*. Since population size increased over time, we weighted each observation by the total number of births experienced. Continuous variables were centered about the mean to decrease concerns about multicollinearity and facilitate interpretation. Each model also controlled for the relevant estimation flag.

Results

Descriptive

Descriptive statistics are in Table 1. Note the greater variability in SRB for Salt Lake County, likely due to smaller population sizes compared to Utah as a whole. This can be seen visually in Figures 1 and 2, which chart SRB with the total number of births. The axes for both figures are scaled the same, so it can be visually seen that the number of births for the rest of Utah is much larger than Salt Lake County. Note the sex ratios hover about 1.05, as would be expected.

Correlations

The correlation matrix between secondary sex ratio and the GSL measures are shown in Table 2. As expected, elevation, river inflows and precipitation are positively correlated with each other, but negatively correlated with evaporation. Note that river inflow's correlations with evaporation and precipitation are weak and insignificant, but the correlation with lake elevation is significant. This may be because while river inflows affect the lake level, they are not affected by localized precipitation and evaporation. Also as expected, SRB positively correlates with elevation and precipitation, but negatively with evaporation. The correlation with river inflows is positive, but weak and insignificant.

Regressions

Table 3 shows the parameter estimates from the full regressions. However, given our interest in the GSL's associations by time and space, the marginal effects shown in Table 4 are of greater interest. For the pre-spike period in Salt Lake County, where we would expect the strongest associations, lake elevation and precipitation are significantly positively associated with SRB, with evaporation showing a significant negative association. Outside of this location and time, those three measures show no statistically significant associations. This is consistent with our hypotheses that GSL measures would correlate with SRB, but most strongly before the Golden Spike and in Salt Lake County. The findings for river inflows, however, show a significant negative association in the pre-spike period, but only for counties other than Salt Lake.

Conclusion

Our findings show that greater water availability, and likely a more productive environment, is positively associated with SRB in Salt Lake County in a natural fertility population. We showed a dose-response relationship where the association decreases with distance from the putative stressor. With the exception of river inflows, our measures of water availability all performed as predicted, with greater availability increasing the SRB. However, these results hold only for the frontier-era and not into the period of rapid industrialization. We argue that the mixed state of the literature may have to do with the fact that the impact and frequency of exogenous stressors are likely dampened in post-industrial societies.

Tables

Table 1. Descriptive Statistics (N=69 Years)

	Mean	SD	Min	Max
Secondary Sex Ratios				
Salt Lake County	1.06	0.07	0.89	1.23
Other Utah Counties	1.05	0.04	0.96	1.16
Great Salt Lake Measures				
Elevation[a]	4204.47	3.59	4197.60	4211.60
River Inflow[b]	2092.94	859.99	396.00	4536.00
Precipitation[c]	10.66	2.66	5.99	19.30
Evaporation[d]	4854.71	326.04	4140.00	5508.00

a. Lake elevation (in feet)
b. River inflows from the Bear, Weber and Jordan rivers (in 1,000 acre-feet)
c. Precipitation on lake (in inches)
d. Freshwater evaporation (in inches)

Table 2. Pearson Correlation Coefficients (P-values) of secondary sex ratio with four measures of Great Salt Lake (N=138 geographic-years).

	SRB	**Elevation**	**River Inflow**	**Precipitation**	**Evaporation**
SRB[a]	1	0.18 *	0.06	0.21 *	-0.19 *
Elevation[b]	0.18 *	1	0.28 ***	0.23 **	-0.22 *
River Inflow[c]	0.06	0.28 ***	1	0.09	-0.05
Precipitation[d]	0.21 *	0.23 **	0.09	1	-0.91 ***
Evaporation[e]	-0.19 *	-0.22 *	-0.05	-0.91 ***	1

a. SRB- Sex ratio at birth (number of live male births / number of live female births)
b. Lake elevation (in feet)
c. River inflows from the Bear, Weber and Jordan rivers (in 1,000 acre-feet)
d. Precipitation on lake (in inches)
e. Freshwater evaporation (in inches)

***p<.001, **p<.01, *p<.05

Table 3. Regressions of Secondary Sex Ratio on Relevant Great Salt Lake Measurement

	Elevation		River Inflow		Precipitation		Evaporation	
	0.0935		0.076		0.0971		0.0651	
	Beta	**P-value**	**Beta**	**P-value**	**Beta**	**P-value**	**Beta**	**P-value**
Intercept	1.04844	<0.0001	1.04935	<0.0001	1.04846	<0.0001	1.05121	<0.0001
r	-0.00052	0.7254	0.00001	0.0697	-0.00052	0.7869	-0.00064	0.6472
t1	-0.03350	0.1179	-0.0118	0.4491	-0.04216	0.0513	-0.01373	0.4067
g1	0.00565	0.5707	0.00432	0.6623	0.00577	0.5607	0.00462	0.6434
rXt1	-0.00196	0.7131	-0.00004	0.0116	0.00148	0.7448	-0.00052	0.9095
rXg1	0.00201	0.4637	0.00000	0.8638	0.00376	0.3864	-0.00087	0.7821
g1Xt1	0.02317	0.4138	0.02300	0.4206	-0.00178	0.9539	0.00036	0.9908
rXt1Xg1	0.02641	0.0169	0.00005	0.0946	0.01408	0.1297	-0.01673	0.0615
flag	0.02561	0.1489	0.00447	0.5988	0.03151	0.0393	n/a	n/a

Table 4. Marginal effects of the relevant GSL measure upon secondary sex ratio, by time and space

Peak Lake Elevation (in feet)			
		Pre-Spike	
		No	Yes
SL Co.	No	-0.00052	-0.00248
	Yes	0.00149	0.02593**

River Inflows (in 1,000 acre-feet)			
		Pre-Spike	
		No	Yes
SL Co.	No	0.00001	-0.00003*
	Yes	0.00001	0.00002

Precipitation on Lake (in inches)			
		Pre-Spike	
		No	Yes
SL Co.	No	-0.00052	0.00096
	Yes	0.00323	0.0188**

Fresh-Water Lake Evaporation (in inches)			
		Pre-Spike	
		No	Yes
SL Co.	No	-0.00064	-0.00001
	Yes	-0.00002	-0.00019**

***p<.001, **p<.01, *p<.05
Significance levels determined by the “test” command with SAS Proc PHREG

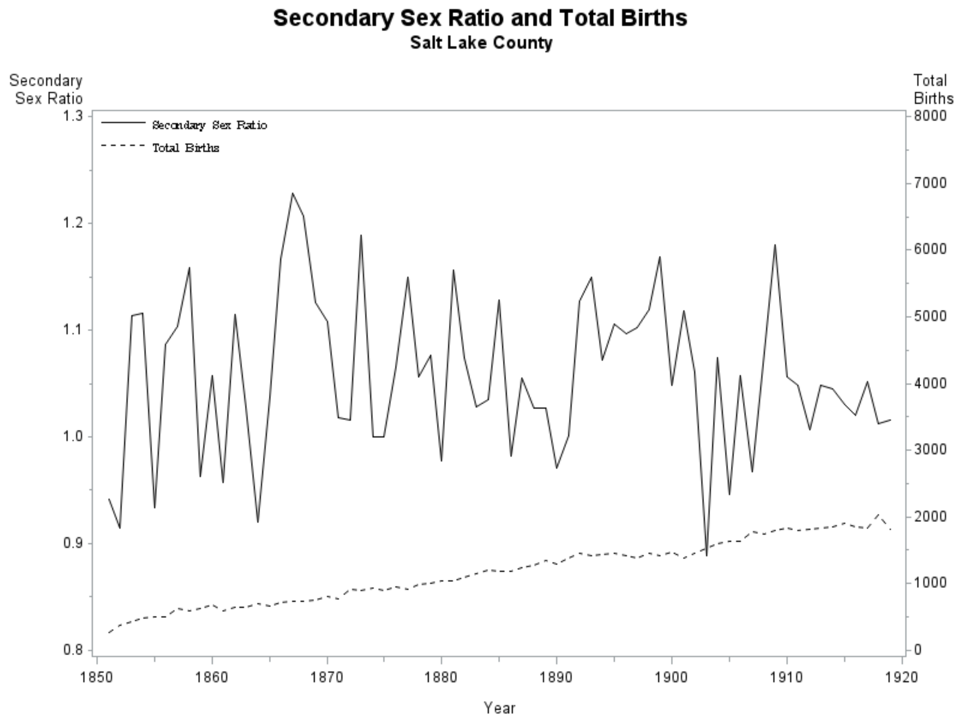

Figure 1

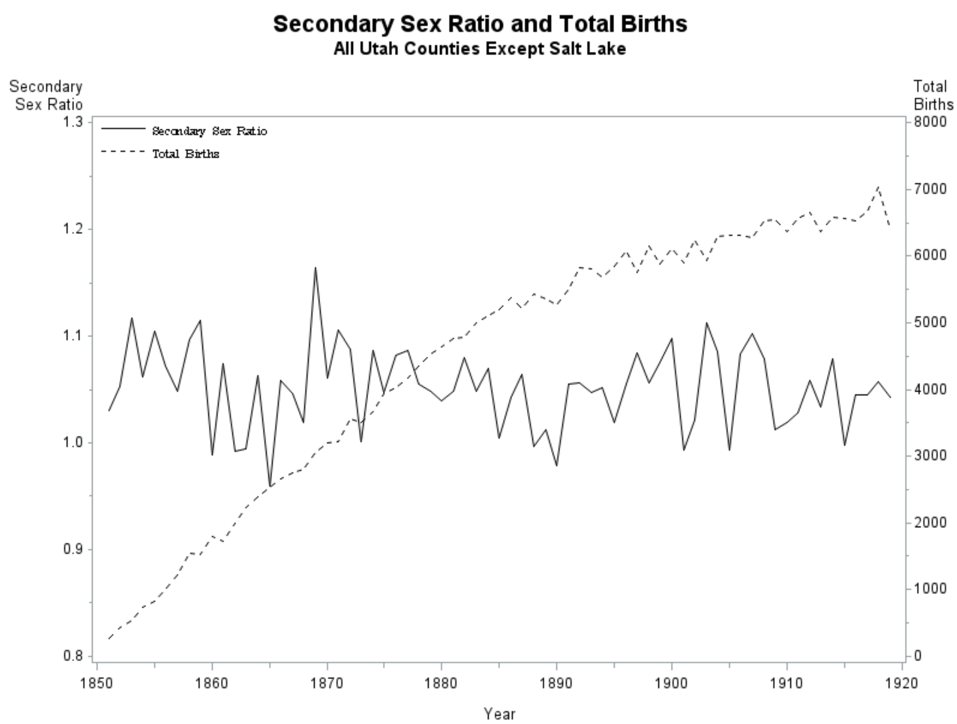

Figure 2

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