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ORIGINAL ARTICLE

Long-term Effects of In Utero Exposure to "The Year without a Summer"

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Abstract

This paper uses the aftermath of the great Tambora eruption in 1815 as a natural experiment to explore the long-term effects of a nutritional shock during prenatal development. The volcanic explosion of Tambora formed substantial ash columns which hampered sunlight, cooled down the surface temperature, reduced the length of the growing season, and led to a severe harvest failure during summer and winter of 1816 in Europe and northeastern states of America. US decennial census 1850 provides evidence that cohorts in utero during the climate anomaly revealed lower literacy rates, lower labor force participation rates, a fewer number of own children, and a higher female-male ratio. The results are confirmed among the same cohorts in England, Canada, and Norway. The decennial census of each country indicates negative effects of exposure during prenatal development on labor market participation rates in adulthood.

Keywords: Fetal origins hypothesis, Public health, Environment and health, Education, Labor market participation

JEL classification: I15, Q51, N31, N51

Introduction

It is now well established that external stressors during prenatal development have adverse short term effects for newborns and negative long-term effects in adulthood.[1] Maternal stress, nutritional deficiency, and pollution during in utero are shown to be associated with infants' health outcomes including low birth weight, preterm birth, birth defects, fetal death, infant mortality, complications in pregnancy, and congenital disorders (Almond, Mazumder, & Van Ewijk, 2014; Almond & Mazumder, 2005; Beach & Hanlon, 2016; Duncan, Mansour, & Rees, 2017; Hoynes, Schanzenbach, & Almond, 2016; Isen, Rossin-Slater, & Walker, 2017; Majid, 2015; NoghaniBehambari et al., 2020c; NoghaniBehambari, Noghani &Tavassoli, 2020a,b; Page, Schaller, & Simon, 2017; Tavassoli, Noghanibehambari, Noghani, & Toranji, 2020; Van Ewijk, 2011). The lower health endowment of the affected individuals transforms the trajectory of their outcomes later in life. It lowers math and cognitive test scores at age 7, decreases the completed years of education, decreases the annual hours worked and labor force participation, diminishes the earnings at age 30, lowers life expectancy, increases the mortality rates, raises the likelihood of old-age mortality due to specific causes of death such as cardiovascular diseases (Almond et al., 2014; den Berg, Lindeboom, & Portrait, 2006; NoghaniBehambari, Noghani &Tavassoli, 2020a,b; Persson & Rossin-Slater, 2018; Yeung, den Berg, Lindeboom, & Portrait, 2014).

There are some empirical challenges to assess the long-term effects of an in utero shock. First, the shock must be orthogonal to other individual and household level covariates including their genetic endowments. Second, the effect of initial health

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[1] Almond and Currie (2011a,b) provide a review of the recent research which investigates the fetal origins of later-life outcomes.

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deficiency is not uniform across the life cycle. It could be revealed only in childhood, adulthood, or old age. The latency of these effects causes a detection problem. Third, families could reimburse or reinforce their children with a lower initial health endowment. The reinforcement of families could push up the estimates of this long-term link since less healthy children are sort out for fewer family resources. These inherent aspects of the question make the non-experimental studies disputable.

The agricultural catastrophe due to the cold summer of 1816 provides a unique opportunity to examine the long-term effects of external shocks during antenatal development. It started with the unanticipated volcanic eruption of Mount Tambora in the Dutch East Indies (nowadays Indonesia) in 1815. The greatest in recorded history, the volcanic ash disseminated over the globe over the months after the eruption. It cooled down the global temperature by 0.4–0.7°C and caused harvest failures across the world (Stothers, 1984). In the US, eastern and northeastern states experienced an unprecedented cold summer in 1816, a year known as "the year without a summer". The harvest failure was so severe in these regions that food prices increased by as much as three times during months afterward. However, western, southern, Midwestern, and northern states were not affected by the climate anomaly (Oppenheimer, 2003).

Using Census data for the year 1850, we show that cohorts who were exposed to the cold summer and the proceeding agricultural failure during prenatal development in affected regions had lower literacy rates and labor force participation in their adulthood. Being exposed to the prenatal shock is associated with 2.6 and 1.4 percentage points decrease in the probability of being literate and active in the labor force, respectively. Furthermore, the exposed individuals have, on average, 0.11 fewer number of children.

Investigating the long-term relation between health endowment in early life and adult outcomes has important policy implications. The significant long-term correlation could suggest public policies to weight more on the fetal period rather than contemporaneous adults' outcomes directly if the target is to enhance education and labor force participation. Second, it could help health policymakers to recognize more vulnerable groups in society. Furthermore, it points to the fact that a welfare program to provide pregnant mothers during times of hardship is not only a health policy but also an education policy or labor force protection policy for the next generations.

This paper makes several contributions to the current literature. First, to the best of our knowledge, this is the first study to evaluate the economic and non-economic impacts of the infamous climate anomaly following the Tambora eruption. Second, it contributes to the environmental economics literature by providing the long-term labor market effects of a roughly 0.5°C reduction in average annual temperature. Third, scant transportation system and lack of government protective policies in the period of this study limit the scope of external deteriorating effects and so provide more accurate estimations of the long-term correlations.

The rest of the paper is organized as follows. In section 1, we provide a brief literature review. Section 2 describes the core dataset, sample selection strategy, and gives summary statistics of the final dataset. Identification strategy and main results are discussed in section 3. In section 4, we go over some robustness checks and show the heterogeneity of the coefficients in different sub-samples. Possible issues and drawbacks of the analysis, some concluding remarks, and suggestions for future research are presented in section 5.

1 A brief literature review

Prenatal shocks to embryos could have adverse impacts on health endowment at birth and through this lower initial health capital affect the outcomes later in life. Almond (2006) exploits the nationwide spread of the 1918 influenza pandemic as a natural experiment and explores its long-term effects during adulthood. He finds that cohorts whose prenatal development period intersected with the pandemic showed lower educational attainments, lower income, lower socioeconomic status, more rates of physical disability, and larger transfer payments in their adulthood ages. Following this paper, Almond and Mazumder (2005) find that cohorts in utero during the spread of the flu illustrate higher rates of impaired health outcomes in old ages compared to cohorts born a few months before or after.

A positive or negative nutritional shock in utero has significant short term and long-term effects. Hoynes et al. (2016) investigate the long-run impacts of participation in the Food Stamp Program. Access to food stamps during early childhood is associated with lower odds of metabolic syndrome and raises the economic self-sufficiency of women in adulthood. The important implication of their paper is the causal effect of a direct policy-driven channel, namely nutrition, during childhood, and health outcomes later in life. A small strand of literature uses fasting during the Islamic holy month of Ramadan as a plausibly exogenous nutritional shock in utero and investigates its impacts later in life. Being exposed to Ramadan during prenatal development is associated with lower birth weight, a fewer number of male births, and a higher likelihood of disability during adulthood (Almond & Mazumder, 2011), reduction in the test scores at age 7 (Almond et al., 2014), an increase in the symptoms indicative of coronary heart problems and type 2 diabetes during old ages (Van Ewijk, 2011), lower cognitive and math test scores at school and fewer working hours during adulthood (Majid, 2015). NoghaniBehambari et al., 2020c investigate the effects of enforcements in child support policies during the 1970s and 1980s in the United States as a pathway to improve the welfare of single mothers and find that this improvement has led to a reduction in infant and child mortality rates. Based on these studies, we expect that a regional harvest failure has adverse health effects on children in utero or their early years of life by reducing nutritional stock available to households.

Famines are widely studied cases to evaluate the long-term effects of malnutrition in utero. Scholte, Van Den Berg, and Lindeboom (2015) explore the outcomes of individuals who were in utero during The Dutch Hunger Winter (1944/45) by sub-interval of gestation. They find negative and significant effects of exposure during the first trimester of gestation on employment outcomes at ages 53 and above. Exposure in the second and third trimester increases the hospitalization rates before retirement. In a similar work, Neelsen and Stratmann (2011) find that exposure to the Greek famine of 1941/42 leads to lower educational attainments for cohorts who experienced the famine in utero or during the first year in life.

Part of this effect can be explained by sharp reductions in income. In various ways, income can have positive effects on birth outcomes. For instance, Noghanibehambari and Salari (2020) show that an increase in income due to changes in Unemployment Insurance (UI) benefits during pregnancy can increase birth weight among UI eligible mothers. They show that a change in health insurance away from public insurance and more towards presumably better quality private health insurance could be some mechanism channels.

A small strand of literature uses exposure to pollution during the antenatal development period and explores its adverse health impacts on newborns and adult outcomes. Isen et al. (2017) use US administrative data to evaluate the long-term effects of the 1970 Clean Air Amendment Act. They exploit the variation in differential exposures of counties that were affected by the act and find that higher exposure in the year of birth is associated with lower earnings and labor force participation at age 30. Chay and Greenstone (2003) use variation in pollution exposure in US counties caused by the 1981–1982 recession to estimate the effects of pollution on infant mortality rates and finds that a 1% reduction in total suspended particulates (TSP) will cause a 0.35% decline in infant mortality. In a similar study, Tavassoli et al. (2020) show that industrial pollution during the late nineteenth and early twentieth century was associated with higher infant mortality as measured by gender ratio.

The effect of these shocks could be deteriorated by parental over or under investment on children. The parental investment could reduce the health endowment gap between their offspring or reinforce this gap if they decide to invest more in their healthier children (Currie, 2011; Frijters, Johnston, Shah, & Shields, 2013; Yi, Heckman, Zhang, & Conti, 2015). Restrepo (2016) finds evidence that low educated parents allocate more resources to their offspring who had initially normal birth weight compared to their low birth weight children, while highly educated mothers compensate for this health gap among their children.

Mortality rates during adulthood and old age could be partly explained by early life nutritional and economic conditions. Yeung et al. (2014) explore this path and find that an adverse income shock caused by a recession during pregnancy and the first year of life will increase the risks of old-age cause-specific mortality. It increases the probability of death due to cancer among males and females by about 8 and 6 percentage points, respectively. Also, it increases the female mortality due to cardiovascular diseases by roughly 5 percentage points. NoghaniBehambari et al. (2020b) investigate the link between early life economic conditions and old-age cause-specific mortality using US data. They show that a 1 percent decrease in the aggregate business cycle in the year of birth is associated with 2.2, 2.3, 3.1, 3.7, 0.9, and 2.1 percent increase in the probability of mortality in old ages due to malignant neoplasms, diabetes mellitus, cardiovascular diseases, influenza, chronic respiratory diseases, and all other diseases, respectively. den Berg et al. (2006) use a longitudinal dataset covering the years 1812–2000 for individuals born in the period 1812–1912 in the Netherlands and document that household economic conditions early in life can explain adult mortality rates. They exploit booms and busts during childhood as an instrument for individual economic conditions. Applying a hazard analysis, they find that being exposed to a boom early in life is associated with a 9% reduction in adult mortality rates. Using the same instrument, van den Berg et al., 2011 show that being born under a recession increases the probability of cardiovascular mortality rates later in life. den Berg, Gupta, van den Berg, and Gupta (2015) introduce a causal pathway for this effect. They show that marital status, as a determinant of adult mortality, is itself affected by economic conditions early in life. Among women, longevity is reduced upon marriage in case they are born under adverse economic conditions. However, marriages have protective effect for men. Married men enjoy longevity, and the marital status does not depend on economic conditions in early life. On the other hand, male mortality rates commove, negatively, with business fluctuations in their early childhood.

Other relevant papers confirm the influence of economic and non-economic conditions during prenatal development and early life on later outcomes (Almond & Currie, 2011a; Banerjee, Duflo, Postel-Vinay, & Watts, 2010; Beach & Hanlon, 2016; Bhalotra, Karlsson, & Nilsson, 2017; Carlson, 2015; Case, Fertig, & Paxson, 2005; Cutler, Miller, & Norton, 2007; den Berg et al., 2006; Duncan et al., 2017; Frijters, Hatton, Martin, & Shields, 2010, 2013; Lin & Liu, 2014; Lindeboom, Portrait, & den Berg, 2010; Maccini & Yang, 2009; Maruyama & Heinesen, 2020; Myrskylä, 2010; Myrskylä, Mehta, & Chang, 2013; NoghaniBehambari, Noghani &Tavassoli, 2020a,b; Olafsson, 2016; Parman, 2015; Strand & Kunst, 2006; Tavassoli et al., 2020; Torche, 2011; Torche & Kleinhaus, 2011; von Hinke Kessler Scholder, Wehby, Lewis, & Zuccolo, 2014).

2 Backround, data, and varibale definitions

2.1 The great Tambora eruption

The explosion of Mount Tambora in 1815 was the largest volcanic eruption in recorded history. It claimed the lives of approximately 88,000 people in the islands close to Sumbawa, Indonesia, the place of occurrence. The following ash eruption was the earth's largest in magnitude since the most recent Ice Age period (Stothers, 1984).

In the year 1816, an unflagging and dry fog shadowed the northeastern parts of the United States. It continued during the spring and summer over a long period on a diurnal basis. A New York report reads “the dry fog reddened and dimmed the sun to such an extent that sunspots became visible to the naked eye” (Stothers, 1984). The haze reduced the sunshine and cooled down the surface temperature. Thus, the length of the growing season almost halved in most regions including Southern Maine, Southern New Hampshire, and Eastern Massachusetts. Snow began to fall in June in Albany, New York, and Dansville, Main. Harsh frosts spread over a wide area from Connecticut and New England to as south as Trenton, New Jersey (Oppenheimer, 2003). The inadequate feeding ground killed much livestock in New England during the winter of 1816–1817 (Baron, 1992).

Briffa and Jones (1992) estimate that the summer temperature across western and central Europe was 1–2°C cooler in 1816 than the average for the period 1810–1819. Post (1977) provides evidence of large increases in indices of wholesale grain prices in Europe and North America which peaked in the year 1816 and subsisted relatively during the following years. The price of bread was so high that even customary wage earners could not afford it. In Europe, the consequences of the Napoleonic Wars aggravated the situation. The harvest failure and subsequent famine triggered social riots in most European cities with the proclamation of “Bread or Blood”. In Canada, however, such social disturbances were not revealed mostly due to an embargo on grain exports between July and September 1816–17 (Post, 1977).

Several features of this phenomenon offer an appropriate context to test the Fetal Origin Hypothesis. First, the weather anomaly arrived completely unprecedented, unforeseen, and without warning. Second, the location of the eruption was too far away to have any direct effect on US mothers. The main channel was the indirect effects which caused a persistent decrease in the sunshine, a fall in the length of the growing season, and finally harvest failure. Third, preliminary trade roots hampered the import of food from neighboring states. The inadequate transportation network isolated the affected regions and aggravated the agricultural damage. Fourth, there are no government interventions or welfare policies in this period to neutralize the shock. Therefore, we expect that the indirect effect coerced only a nutritional effect on pregnant mothers following the crop damage of the 1816 summer. Fifth, the anomaly occurred only in the eastern regions of the US. It leaves the individuals born in other states unaffected and so provides a control group. Comparing individual outcomes during adulthood who were born in eastern and northeastern states versus western, Midwestern, southern, and northwestern states (first difference), and those born in 1817 versus in the proceeding and following years (second difference) can reveal the long-term effect of the in-utero exposure. The only channel for omitted variables to bias the estimated coefficients is that individuals'

Table 1. Summary statistics.

	Birth Place Eastern States		Birth Place West-Northern States	
	(YOB: 1817)	(YOB: 1819)	(YOB: 1817)	(YOB: 1819)
% Active in Labor Force	49.74 (50.00)	50.38 (50.00)	53.02 (49.92)	53.29 (49.90)
% Literate	92.67 (26.07)	93.45 (24.75)	72.19 (44.81)	74.39 (43.66)
% Female	48.13 (49.97)	47.44 (49.93)	45.04 (49.76)	44.34 (49.69)
No. of Children	2.019 (1.972)	1.864 (1.826)	2.408 (2.313)	2.267 (2.142)
% Whites	95.99 (19.62)	96.59 (18.15)	87.93 (32.58)	90.02 (29.98)
Number of Cases	166,859	140,632	3,546	3,207

Note: Standard deviations are reported in parentheses.

idiosyncratic shocks commove positively with year-regions that were affected and negatively with year-regions that were not.

2.2 Sample construction

In order to assess its socioeconomic effects, we use individual-level data from Census 1850 (100%). The data are extracted from Ruggles, Genadek, Goeken, Grover, and Sobek (2017). In the main analysis, we restrict the cohorts to those who were born between the years 1810–1820. However, the results are robust to changes in the rolling window. Due to data limitations, we refer to historical reports and historical climate and temperature reconstruction studies in order to identify the exposed and non-exposed regions. The main climate anomaly had been observed in eastern and northeastern regions while western, southern, mid-western, and northwestern states had not been affected (Keith R Briffa, Jones, Schweingruber, & Osborn, 1998; Lough, 1992; Oppenheimer, 2003). Therefore, we divide the sample into two regions: states that were mentioned in historical records and definitely exposed to the weather anomaly, and immune states locates in other areas.[2]

Since the main increase in grain prices commenced circa summer, fall, and winter of 1816–1817, cohorts who were born in 1817 should have experienced the nutritional shock during prenatal development. Therefore, 1817-born cohorts in affected regions constitute the treatment groups while other cohorts serve as the control groups. In a robustness check, we exchange the control group by cohorts born during 1816–1818, combined 1816 through 1818, and combined 1817–1818, separately, and show that the most affected groups are actually the 1817-born cohorts.

A summary of the characteristics of the final sample is reported in Table 1 for two illustrative cohorts born in 1817 and 1819. The average labor force participation rate for 1817-born cohorts in affected regions are, qualitatively, lower than all other cohorts. Their average literacy rates during adulthood are lower compared to the 1819-born persons in the same states. The ratio of females is the most compared to all other cohorts. Their number of children, however, does not follow this pattern.

3 Empirical model and main results

In order to capture the average outcomes of adult cohorts who were born in 1817 in states exposed to the harvest failure of 1816, we run different formulations of the following Difference-in-Difference model:

$$y_{isz} = \beta_0 + \beta_1 YOB1817_i + \beta_2 SOBexp_i + \beta_3 YOB1817_i \times SOBexp_i + \beta_4 X_i + G(YOB_i) + \zeta_s + \xi_z + \epsilon_{isz} \tag{1}$$

where i indexes the individual, s the current state of residence, and z the state of birth. y refers to individual outcomes including activity status in the labor force, literacy, gender, and the number of own children. The indicator $YOB1817$ equals one if the individual is born in the year 1817 and zero otherwise. $SOBexp$ contains a set of dummies to identify the exposed regions as explained in section 2.2. Some individuals' characteristics are captured in X including a fourth polynomial function of age, Duncan Socioeconomic Index (SEI),[3] and race. $G(.)$ is a third-degree polynomial function to capture the secular trends in the birth year. Besides, for each outcome, we also include other related outcomes as

[2] Identified exposed states are: Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut, New Jersey, Delaware, Maryland, Virginia, New York, Pennsylvania, West Virginia, North Carolina; while the following states are recognized as the unaffected regions: Minnesota, Texas, New Mexico, Arizona, Nevada, California, Colorado, Kansas, Oklahoma, Missouri, Arkansas, North Dakota, South Dakota, Wyoming, Idaho, Montana, Washington, Utah, Nebraska, Iowa, Louisiana.

[3] Duncan Socioeconomic Index or equivalently SEI is a constructed score for each occupation based on the income and education level for that occupation. The higher the index, the higher the presumed socioeconomic class of the person. The score varies from 1 to 96 (top coded).

the control variables. Specifically, for the outcome literacy, we control for the person's gender. For the outcome labor force participation, we control for gender, literacy, and number of own children. Finally, for the outcome number of own children, we control for gender and literacy. In ζ and ξ are included a set of dummies for the current state of residence and another set for the state of birth. Finally, ϵ is a disturbance term. All standard errors are clustered on the place of birth.

If individuals' idiosyncratic error terms, e.g. the family genetic inheritance, varies systematically for the 1817-born cohort in affected regions compared to other cohorts, then equation (1) suffers from omitted variable bias. However, the eruption happened without warning and to an unprecedented degree. The anomaly has not been experienced over the past hundreds of years.[4] Therefore, its outbreak and regional variation were perfectly orthogonal to individuals and household characteristics.

Male embryos are more susceptible to external shocks during the antenatal period. Therefore, harsh circumstances are associated with a higher ratio of females in live births due to higher fetal death and infant mortality among male newborns. Hence, the gender ratio (female-male) has been used as a proxy for infant mortality (Sanders & Stoecker, 2011).[5,6]

The main results of regressions introduced in equation (1) are presented in Table 2. Shown in the full specification in column 2 of each panel, exposure to the climate anomaly during prenatal development is associated with 1.2 percentage points lower probability to participate in the labor force, 2.7 percentage points lower probability of being literate, 0.10 fewer children, and 1.1 basis points higher likelihood of being female observed during adulthood. These numbers are equivalent to 2.4, 2.3, 3.6, and 4.4 percent change from the mean of labor force participation, gender ratio, literacy, and the number of children, respectively. Whether or not including individual characteristics and fixed effects, the coefficients are significant at the conventional levels.

Since the gender ratio is used to a proxy infant mortality and fetal death, a higher likelihood of being female (i.e. a higher female-male ratio) implies higher rates of mortality among newborns who were in utero during the cold summer. Lower labor force participation and education (proxied by literacy rates) have been linked to initial health endowments by several studies that explored the Fetal Origin Hypothesis (Almond & Currie, 2011a,b). These results suggest that there are long-term consequences for those cohorts in utero during the harvest failure of summer and winter of 1816–1817.

4 Robustness checks

In this section, we go over some alternative specifications to check the robustness of the main results. As shown in Post (1977), the wholesale grain prices peaked in 1816 and subsided in the following years. However, they did not reach the initial levels until 1819. Therefore, cohorts born even two years after the harvest failure could still be affected. We replace the treated time in equation (1) with a different combination of cohorts born between 1816 and 1818, separately. The results are shown in Table 3 and Table 4. The impacts are more pronounced for birth cohorts 1817 who experienced the 1816 summer and winter in utero. There is no evidence of an impact on the 1816-birth cohorts. As shown in the first panel of Table 3, the 1818-born cohorts reveal lower labor force participation and the coefficient is significant. Still, its magnitude is slightly lower than that of the 1817-born cohorts. Aggregating both 1817- and 1818-birth cohorts boost the marginal effects. The exposed cohorts who were born between the years 1817 and 1818 have 1.4 percentage points lower likelihood of participation in the labor force during adulthood.

The second panel illustrates the results of literacy. Although the coefficients of the 1816- and 1818-born cohorts are negative, they are not significant. The reduction in literacy occurred only for those in utero during the harvest failure, i.e. 1817-cohorts, and for the 1817–18 aggregated cohorts. Similar results are obtained for the number of children and gender. Depicted in the left panel of Table 4, the effects on the number of children are negative but insignificant. The increase in the probability of being a female, as shown in the right panel, is the same for 1817-born cohorts and 1818-born cohorts. Using 1817–1818 year of birth as the treated time reveals quite a similar marginal effect (0.9 percentage points versus 0.8 percentage points).

Next, we split the sample by race and gender and run the full specification model for each group individually. The results are illustrated in Table 5

[4] As stated in Oppenheimer (2003) and Briffa and Jones (1992), the cold summer of 1816 was the coldest of the past six centuries.

[5] Some evidence and application of this fact is provided in the literature (Almond & Edlund, 2007; Bruckner & Catalano, 2007; Torche & Kleinhaus, 2011).

[6] Almond and Mazumder (2011) use in utero exposure to Ramadan, the holy month of Muslims in which they fast from sunrise to sunset, as a natural experiment and find that the nutritional shock has negative health effects on newborns. However, in a longer horizon analysis, they also show that exposed individuals have higher female to male ratio. The sex composition in the adulthood could point to the initial gender ratio bias at birth.

Table 2. Long-term effects of in utero exposure to the cold summer-winter of 1816.

	Labor Force Participation		Gender (Female = 1)		Literacy		Number of Children	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Treated States × Birth Year 1817	−0.021*** (0.006)	−0.012** (0.005)	0.020*** (0.006)	0.011** (0.004)	−0.060** (0.025)	−0.027*** (0.006)	−0.226 (0.282)	−0.102** (0.043)
Treated States	−0.011* (0.006)	0.110 (0.256)	0.013* (0.006)	−0.182 (0.129)	0.267*** (0.025)	−0.022 (0.025)	−0.151 (0.282)	−3.159** (1.467)
Birth Year 1817	0.024*** (0.006)	0.014** (0.005)	−0.020*** (0.006)	−0.009** (0.004)	0.069*** (0.024)	0.030*** (0.006)	−0.148 (0.188)	0.121*** (0.038)
Duncan Socioeconomic index		0.018*** (0.000)		−0.017*** (0.000)		0.001*** (0.000)		−0.009*** (0.001)
Race: White		−0.133*** (0.011)		0.085*** (0.007)		0.352*** (0.017)		0.550*** (0.065)
F (Birth Year)	No	Yes	No	Yes	No	Yes	No	Yes
Year FE	No	Yes	No	Yes	No	Yes	No	Yes
State of Birth FE	No	Yes	No	Yes	No	Yes	No	Yes
State of Residence FE	No	Yes	No	Yes	No	Yes	No	Yes
G (Age)	No	Yes	No	Yes	No	Yes	No	Yes
Number of Cases	1,242,262	1,242,262	1,242,262	1,242,262	902,225	902,225	1,242,262	1,242,262

Note: Standard errors, clustered on the state of birth, are reported in parentheses. $F(.)$ is a third-degree polynomial. $G(.)$ is a quadratic polynomial. Controls for labor force participation include: race dummies, Duncan Socioeconomic index, number of children, literacy, and gender. Controls for Literacy include: race dummies, Duncan Socioeconomic index, and gender. Controls for Number of Children include: race dummies, Duncan Socioeconomic index, literacy, and gender. Controls for Gender include: race dummies, and Duncan Socioeconomic index.

Table 3. Long-term effects of in utero exposure to the cold summer of 1816 for different threshold of time treatment.

	Labor Force Participation					Literacy				
	YOB = 1816	YOB = 1817	YOB = 1818	YOB = 1816-18	YOB = 1817-18	YOB = 1816	YOB = 1817	YOB = 1818	YOB = 1816-18	YOB = 1817-18
Treated States × Birth year 1816	0.004 (0.004)					−0.005 (0.007)				
Treated States × Birth year 1817		−0.012** (0.005)					−0.028*** (0.006)			
Treated States × Birth year 1818			−0.011** (0.005)					0.003 (0.007)		
Treated States × Birth year 1816−18				−0.006 (0.008)					−0.013 (0.010)	
Treated States × Birth year 1817−18					−0.014** (0.007)					−0.023* (0.012)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State of Birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State of Residence FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F(Birth Year)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
G (Age)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,242,262	1,242,262	1,242,262	1,242,262	1,242,262	902,225	902,225	902,225	902,225	902,225

Note: Standard errors, clustered on the state of birth, are reported in parentheses. $F(.)$ is a third-degree polynomial. $G(.)$ is a quadratic polynomial. Controls for labor force participation include: race dummies, Duncan Socioeconomic index, number of children, literacy, and gender. Controls for Literacy include: race dummies, Duncan Socioeconomic index, and gender. Controls for Number of Children include: race dummies, Duncan Socioeconomic index, literacy, and gender. Controls for Gender include: race dummies, and Duncan Socioeconomic index. While only the interaction coefficients are shown, the main effects are included in all regressions.

Table 4. Long-term effects of in utero exposure to the cold summer of 1816 for different threshold of time treatment.

	Number of Children					Gender (Female = 1)				
	YOB = 1816	YOB = 1817	YOB = 1818	YOB = 1816-18	YOB = 1817-18	YOB = 1816	YOB = 1817	YOB = 1818	YOB = 1816-18	YOB = 1817-18
Treated States × Birth year 1816	−0.032 (0.036)					−0.005 (0.004)				
Treated States × Birth year 1817		−0.029 (0.040)					0.008** (0.004)			
Treated States × Birth year 1818			−0.042 (0.045)					0.008** (0.004)		
Treated States × Birth year 1816−18				−0.071 (0.056)					0.003 (0.006)	
Treated States × Birth year 1817−18					−0.046 (0.057)					0.009* (0.005)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State of Birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State of Residence FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F(Birth Year)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
G (Age)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,242,262	1,242,262	1,242,262	1,242,262	1,242,262	1,242,262	1,242,262	1,242,262	1,242,262	1,242,262

Note: Standard errors, clustered on the state of birth, are reported in parentheses. $F(.)$ is a third-degree polynomial. $G(.)$ is a quadratic polynomial. Controls for labor force participation include: race dummies, Duncan Socioeconomic index, number of children, literacy, and gender. Controls for Literacy include: race dummies, Duncan Socioeconomic index, and gender. Controls for Number of Children include: race dummies, Duncan Socioeconomic index, literacy, and gender. Controls for Gender include: race dummies, and Duncan Socioeconomic index. While only the interaction coefficients are shown, the main effects are included in all regressions.

Table 5. Long-term effects of in utero exposure to the cold summer of 1816 for different race-gender groups, outcome: labor force participation.

DV: Labor Force Participation	White		Non-White		Males		Females	
	(1) b/se	(2) b/se	(1) b/se	(2) b/se	(1) b/se	(2) b/se	(1) b/se	(2) b/se
Treated States × Birth Year 1817	−0.007 (0.006)	−0.007 (0.005)	−0.004 (0.013)	−0.005 (0.010)	−0.008* (0.004)	−0.008* (0.004)	−0.010* (0.005)	−0.010* (0.005)
Birth Year 1817	0.005 (0.005)	0.010** (0.004)	0.016 (0.012)	0.020* (0.009)	0.008* (0.004)	0.012*** (0.004)	0.011* (0.005)	0.011* (0.006)
Treated States	0.015 (0.314)	0.258 (0.261)	0.279 (0.251)	−0.330 (0.376)	0.549* (0.311)	0.566* (0.323)	−0.300 (0.254)	−0.200 (0.276)
Controls	No	Yes	No	Yes	No	Yes	No	Yes
F (Birth Year)	No	Yes	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State of Birth FE	No	Yes	No	Yes	No	Yes	No	Yes
State of Residence FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
G (Age)	No	Yes	No	Yes	No	Yes	No	Yes
Observations	1,105,262	1,105,262	42,820	42,820	595,352	595,352	552,730	552,730

Note: Standard errors, clustered on the state of birth, are reported in parentheses. $F(.)$ is a third-degree polynomial. $G(.)$ is a quadratic polynomial. Controls for labor force participation include: race dummies, Duncan Socioeconomic index, number of children, literacy, and gender.

Table 6. Long-term effects of in utero exposure to the cold summer of 1816 for different race-gender groups, outcome: literacy.

DV: Literacy	White		Non-White		Males		Females	
	(1) b/se	(2) b/se	(1) b/se	(2) b/se	(1) b/se	(2) b/se	(1) b/se	(2) b/se
Treated States × Birth Year 1817	−0.015** (0.007)	−0.016** (0.006)	−0.031 (0.028)	−0.032 (0.024)	−0.008 (0.011)	−0.007 (0.008)	−0.023* (0.011)	−0.022** (0.007)
Birth Year 1817	0.016** (0.007)	0.014** (0.006)	0.047* (0.027)	0.034 (0.023)	0.014 (0.010)	0.012 (0.007)	0.029** (0.010)	0.025*** (0.007)
Treated States	−0.159*** (0.014)	−0.039* (0.020)	0.220*** (0.063)	−0.327 (0.375)	0.312 (0.371)	0.371 (0.292)	−0.156*** (0.015)	−0.059*** (0.014)
F (Birth Year)	No	Yes	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State of Birth FE	No	Yes	No	Yes	No	Yes	No	Yes
State of Residence FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
G (Age)	No	Yes	No	Yes	No	Yes	No	Yes
Number of Cases	871,807	871,807	30,999	30,999	465,831	465,831	436,975	436,975

Note: Standard errors, clustered on the state of birth, are reported in parentheses. $F(.)$ is a third-degree polynomial. $G(.)$ is a quadratic polynomial. Controls for Literacy include: race dummies, Duncan Socioeconomic index, and gender.

Table 7. Long-term effects of in utero exposure to the cold summer of 1816 for different race-gender groups, outcome: number of children.

DV: Number of Children	White		Non-White		Males		Females	
	(1) b/se	(2) b/se	(1) b/se	(2) b/se	(1) b/se	(2) b/se	(1) b/se	(2) b/se
Treated States × Birth Year 1817	−0.068 (0.148)	−0.051 (0.044)	0.195 (0.146)	0.224*** (0.060)	−0.029 (0.153)	0.014 (0.055)	−0.142 (0.128)	−0.110** (0.049)
Birth Year 1817	−0.109 (0.099)	0.093** (0.040)	−0.049 (0.106)	−0.084* (0.047)	−0.155 (0.097)	0.054 (0.053)	0.004 (0.086)	0.153*** (0.043)
Treated States	1.572*** (0.306)	−0.298 (0.333)	−1.905 (2.266)	−1.365 (1.280)	−0.781 (2.019)	−2.604 (1.895)	−0.355 (1.058)	−0.713 (0.777)
F (Birth Year)	No	Yes	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State of Birth FE	No	Yes	No	Yes	No	Yes	No	Yes
State of Residence FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
G (Age)	No	Yes	No	Yes	No	Yes	No	Yes
Number of Cases	1,181,861	1,181,861	60,453	60,453	644,019	644,019	598,295	598,295

Note: Standard errors, clustered on the state of birth, are reported in parentheses. $F(.)$ is a third-degree polynomial. $G(.)$ is a quadratic polynomial. Controls for Number of Children include: race dummies, Duncan Socioeconomic index, literacy, and gender.

through Table 7. Females are the most affected groups regarding literacy, labor outcomes, and the number of children. Literacy outcome of whites shows significant reductions due to the exposure, while the effects on their labor market status are insignificant (see Table 6).

The only anomaly in the sensitivity results appears in nonwhites for the outcome of number of children in Table 7. This coefficient is positive and statistically significant at a 5 percent level. Since this effect is not consistent with other findings and appears only in one subsample and only for one outcome, we do not believe that it negatively affects the overall findings of this paper.

4.1 Exposure and labor outcomes in England, Canada, and Norway

The cold summer of 1816 affected most parts of the northern hemisphere. The famine due to harvest failure combined with social disturbances was reported in most of west, north, and central Europe. The typhus epidemic that accompanied the famine was reported in almost every village and town in England (Post, 1977). In Montreal, Canada, snowfall started at the beginning of June. In Quebec, 30 cm snow was accumulated in the middle of 1816 summer. Based on this evidence, as a robustness check to the main findings in the US, we use census data of other countries to check the exposure effects on later life labor force participation. However, the choice of the outcome and the countries in this section are limited by data availability. We use 1881 census data for Canada, 1865 census data for Norway, and 1851 census data for England.[7] All these censuses are based on a 100% sample.

To examine the effect of climate anomaly and its aftermath during 1816–1817, we use a cohort analysis explained by the following equation:

$$y_{idz} = \beta_0 + \beta_1 I(YOB = 1817) + \beta_2 I(YOB = 1818) + \beta_4 X_i + G(YOB_i) + \zeta_d + \xi_z + \nu_{idz} \quad (2)$$

In this formulation, $I(.)$ is an indicator function, z indexes the country of birth, and d indexes the sub-district residence of individual i.[8] Establishing a causal relation in equation (2) is hampered for a couple of reasons. The first is the lack of region-specific variation. If the cooler summers and more ruin of the harvest occurred in regions in which lower socioeconomic households live, then the coefficients β_1 and β_2 only show a spurious correlation since such families would have had children with lower initial health endowment even if the cold summer had not taken place. Second, there are universal changes in cohort quality and nationwide factors, e.g. macroeconomic conditions that affect all individuals uniformly. This equation fails to distinguish between cohort-specific universal changes from the pure effect of harvest failure. Third, fertility decisions could have responded to the climate anomaly. This will cause a selection issue if there are correlations between their decision to childbearing during hard times and their characteristics. If households with higher socioeconomic status choose to have children even at the time of agricultural calamities and lower socioeconomic status households postpone the fertility timing, then the coefficients will underestimate the true effects. The best way to analyze the effects is to have longitudinal data that cover households' information before and after the harvest failure. However, such datasets are scarce specifically during the very early years of the nineteenth century.

The correlational link between the climate crisis exposure in utero and labor force outcomes in adulthood are presented in Table 8. The first column of each panel reports the coefficients for a regression including polynomial functions for age and birth year. This is quite similar to the baseline cohort analysis in the literature (Almond, 2006). Exposed individuals show, on average, 0.9 percentage points, 0.7 percentage points, and 0.2 percentage points lower participation rates in Canada, Norway, and England,[9] if born in 1817. The negative long-term effects are statistically significant and relatively large. Being born in 1818 has quite similar effects in Norway and England, but insignificant effects for Canadian individuals. These results suggest that the climate anomaly and subsequent harvest failure in Europe and North America had considerable long-term effects. Recall that the average temperature in 1816 summer was 1–2°C cooler than 1810s averages (Oppenheimer, 2003). This summer temperature reduction affected the health endowment of in utero cohorts due to the negative nutritional shock to pregnant mothers. As a result, the 1817-born generation revealed adverse labor force outcomes

[7] On the contrary to the US census, other outcomes or control variables are not available in these censuses. In the regressions, we only control for gender that is the only available variable. We choose these years based on data availability for the year with 100% sample counts, as well as availability of labor force participation status.

[8] The region of residence is specific to each country and restricted to data availability in country-specific census. We use the most disaggregated regions: county for England and Wales, Province for Norway, and district for Canada.

[9] The census data covers England and Wales together.

Table 8. Long-term effects of in utero exposure to the cold summer of 1816 in Norway, England, and Canada.

Labor Force	Canada			Norway			England		
Participation	(1) b/se	(2) b/se	(3) b/se	(1) b/se	(2) b/se	(3) b/se	(1) b/se	(2) b/se	(3) b/se
Birth Year 1817	−0.011** (0.005)	−0.011** (0.005)	−0.009** (0.005)	−0.008* (0.004)	−0.007* (0.004)	−0.007* (0.004)	−0.002** (0.001)	−0.002* (0.001)	−0.002* (0.001)
Birth Year 1818	−0.005 (0.005)	−0.005 (0.005)	−0.006 (0.005)	0.007 (0.004)	0.007* (0.004)	0.007* (0.004)	−0.005*** (0.001)	−0.001 (0.001)	−0.005*** (0.001)
F (Birth Year)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Region FE	No	No	Yes	No	No	Yes	No	No	Yes
Country of Birth FE	No	No	Yes	No	No	Yes	No	No	Yes
G (Age)	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Number of Cases	130,719	130,719	130,719	160,528	160,528	160,528	2,396,671	2,396,671	2,396,671

Note: Standard errors, clustered on the state of birth, are reported in parentheses. $F(.)$ is a third-degree polynomial. $G(.)$ is a quadratic polynomial. The regressions also control for gender.

compared to non-exposed cohorts born just before and after the shock. This evidence can support the negative effects found among individual outcomes in the United States.

5 Discussion and conclusion

Initial health endowment at birth has significant predictive power for a broad array of individuals' later life outcomes. For instance, a nutritional shock during prenatal development can leave newborns with lower health capital at birth. Through this channel, it taints individuals' outcomes during adulthood. Chief among these outcomes are education and labor force participation. The main challenge in this study is to find a shock to pregnant mothers strong enough that affects the health endowment of newborns and meanwhile orthogonal to mothers' characteristics. This paper explores this question using a plausibly exogenous shock during the early 19th century: the great Tambora eruption in 1815, the largest eruption in recorded history. Although occurred in Indonesia, the aftermath ash columns were so large that they spread over the globe. The formed haze located above the troposphere hampered the sunshine and led to a severe temperature reduction in the summer and winter of 1816–17. The cooling summer and diminished length of growing season resulted in dreadful harvest failure. The climate anomaly affected most eastern and northeastern US states, while it did not reach the southern, western, midwestern, and northwestern states. The exogenous nature of the haze that was uncorrelated with individuals' characteristics at exposed region-years, the lack of governmental protective policy, high latitude location of the haze which rules out the possibility of direct effects through pollution, and inadequate trade roots provide an isolated and exogenous nutritional shock to pregnant mothers. Using census data covering the years 1850–1880, we show that in utero exposure to agricultural failure due to this climate anomaly had statistically and economically significant effects on later life outcomes.

Exposed cohorts revealed, on average, 1.2 percentage points lower likelihood of being active in the labor force, 2.6 percentage points lower probability of being literate, and 0.8 percentage points higher likelihood of being a female. The effects are more pronounced for 1817-born cohorts compared to a case in which 1816- and 1818-born individuals are considered the treated cohorts. A gender decomposition shows that females are more affected by the climate shock. A race decomposition shows that literacy outcomes of whites were influenced to a considerably larger degree by the shock compared to nonwhites. As an alternative check, we used census data of three other affected countries, namely England, Norway, and Canada. Applying a simple cohort analysis, we found that 1817-born cohorts who were exposed in utero to the harvest failure of summer and winter of 1816–17 illustrate lower labor force participation rates during their adulthood years.

All in all, there are some drawbacks in this study that hinder a causal link. First, the estimated coefficients show only the average treatment effect on the treated cohorts. No heterogeneity is identified across individuals. In order to build up individual-specific shocks, it requires information on individuals and households before and after the weather irregularity. Moreover, it should track individuals into their adulthood. Such a dataset simply does not exist in the early years of the 19th century. More importantly, the main channel through which the nutritional shock could affect individuals' outcomes is the initial health endowment. A good approach is to provide evidence of this first stage effect. For example, the effects on fetal death, maternal mortality, birth outcomes, and infant mortality could be proxied for initial health endowments. Again, lack of data impedes such estimates. Second, households might respond to shock in two ways. They could postpone fertility decisions in order to have healthier and more productive children. If this fertility timing is correlated with households' characteristics, like socioeconomic status, then the long-term estimates suffer from selection issues. Another channel is reimbursement or reinforcement behavior of families as a response to the initial health status of children. If households over-invest in their healthier children and allocate fewer resources to their children with lower initial health endowment, then the long-term coefficients overstate the true effects. More noticeably, if such reinforcement behavior is correlated with families' features, like socioeconomic status, or mothers' characteristics, like education, the estimations will be biased.

The third issue comes from the nature of the long-term analysis. Those individuals with low health endowment show, on average, higher rates of fetal death, infant mortality, and toddler mortality. The mortality rates could potentially sort out stronger individuals to reach adulthood, the period in which their outcomes are observed. This selection issue will bias the coefficients and understate the true effects.

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