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Seonghoon KIM

Singapore Management University, SEONGHOONKIM@smu.edu.sg

Belton FLEISHER

Ohio State University - Main Campus

Jessica Ya SUN

Singapore Management University, yasun@smu.edu.sg

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THE LONG-TERM HEALTH EFFECTS OF FETAL MALNUTRITION: EVIDENCE FROM THE 1959–1961 CHINA GREAT LEAP FORWARD FAMINE

SEONGHOON KIM^{a,*}, BELTON FLEISHER^b and JESSICA YA SUN^a

^a*School of Economics, Singapore Management University, Singapore*

^b*Department of Economics, Ohio State University, Columbus, OH, USA*

ABSTRACT

We report evidence of long-term adverse health impacts of fetal malnutrition exposure of middle-aged survivors of the 1959–1961 China Famine using data from the China Health and Retirement Longitudinal Study. We find that fetal exposure to malnutrition has large and long-lasting impacts on both physical health and cognitive abilities, including the risks of suffering a stroke, physical disabilities in speech, walking and vision, and measures of mental acuity even half a century after the tragic event. Our findings imply that policies and programs that improve the nutritional status of pregnant women yield benefits on the health of a fetus that extend through the life cycle in the form of reduced physical and mental impairment.

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KEY WORDS: fetal origin hypothesis; malnutrition; health; China Famine

1. INTRODUCTION

Malnutrition among pregnant women and children has been a long-standing problem in developing countries. For example, China, although achieving impressive economic development, still has more than 120 million individuals suffering from malnutrition and 7.2 million children with stunted growth (Chen, 2013). The ‘Fetal Origins Hypothesis’ of Barker (1990) and much subsequent work argue that fetal malnutrition ‘programs’ the fetus with metabolic characteristics that can lead to future diseases. In the absence of human-subject randomized controlled experiments that might establish a causal link between fetal malnutrition and later life health outcomes, historical events such as the Dutch Famine of 1944 (Roseboom *et al.*, 2001; Scholte *et al.*, 2015) have provided researchers with data permitting the study of the long-term effects of fetal malnutrition. The 1959–1961 China Great Leap Forward Famine (hereafter China Famine), being the worst famine in human history, caused about 30 million excess deaths (Li and Yang, 2005). The dramatic differences in famine intensity across cohorts and regions make the China Famine a particularly well-suited quasi-natural experiment to identify the causal influences of fetal exposure to malnutrition on subsequent physical and mental health outcomes.

We contribute to the literature by examining the long-term health effects of fetal malnutrition in a recently available and large sample of China Famine survivors who were in their 50s by the time of the survey. Studies have shown that infants who experienced malnutrition during the fetal period may be born with normal birth weight and birth size but appear to suffer from various diseases, such as cardiovascular diseases, diabetes, and breast cancer in a later stage of life, because the initial adaptations of DNA to help the survival of a fetus can trigger health problems in later adulthood (Scholte *et al.*, 2015; Lumey *et al.*, 2011; Schulz, 2010). For example, the Dutch

Famine studies suggest that the adverse influences of *in utero* exposure to malnutrition on cognitive abilities became obvious when survivors turned into their 50s, even though no significant effects were seen during their 20s (Stein *et al.*, 1972; Scholte *et al.*, 2015). The delayed effects of prenatal influences are likely to have prevented earlier studies of the China Famine from identifying the full negative consequences of fetal malnutrition, because the age range of famine victims in earlier studies was largely younger than 40 years of age.

Half a century after the event, we are now able to examine the long-term impacts of *in utero* malnutrition on health outcomes of the survivors in their middle age with nationwide panel data on the Chinese elderly, called the China Health and Retirement Longitudinal Study (CHARLS). CHARLS is a biannual panel survey that began in 2011 and collects rich information on a wide array of detailed objective and subjective health measures of a representative national sample of individuals who were aged 45 and over in China. CHARLS has much richer information on various health measures than the China Population Census data and has a much larger sample than the China Health and Nutrition Study (CHNS) data.

There are several studies on the health effects of the China Famine, but they use relatively simple measures such as height and weight observed at early adulthood (Gorgens *et al.*, 2007; Chen and Zhou, 2007; Meng and Qian, 2009; Fung and Ha, 2010), or they look at other health measures using a limited sample (e.g., data obtained from a local hospital) (Clair *et al.*, 2005; Xu *et al.*, 2009). There has been little, if any, comprehensive evaluation of the occurrence and magnitude of long-term health consequences of the China Famine, and the newly available CHARLS data allow us to evaluate these outcomes.

We identify the long-term health effects of fetal malnutrition using province-specific and year-specific death rates weighted by birth month as a proxy for the famine severity. We find that fetal exposure to the China Famine of individuals born during 1959–1961 has led to a 23.3% greater likelihood of developing a speech impediment, a 16% greater likelihood of suffering difficulty in walking, and a 5.1% greater chance of developing vision impairment later in life compared with individuals who were born before or after the China Famine. We also find that survivors who experienced the famine *in utero* have a higher probability of having suffered from a stroke compared with non-famine cohorts.

Consistent with the findings of the Dutch Famine studies, our results show that the survivors of the China Famine have a higher probability of low cognitive function. Survivors who experienced the famine *in utero* tend to perform much worse on simple arithmetic calculations and date recall tests. Because pregnancy is the critical period of time when the nervous system is developing and the human body of the pregnant women prioritizes the survival of a fetus over its brain development, malnutrition experience during the gestation can cause defects in the formation of famine survivors' neural system (Schulz, 2010).¹

The remainder of the paper is structured as follows. In Section 2, we briefly discuss the background of the 1959–1961 China Famine and review the related literature. In Section 3, we describe the data and report sample statistics. Section 4 lays out our empirical strategy for estimating the long-term effects of fetal malnutrition on physical and cognitive outcomes. Section 5 presents and discusses the estimation results. Section 6 concludes the paper.

2. BRIEF BACKGROUND AND RELATED LITERATURE ON THE 1959–1961 GREAT LEAP FORWARD FAMINE

2.1. Brief background

In 1958, the Chinese Communist Party implemented a set of nationwide policies, known as the Great Leap Forward Movement, aiming to quickly catch up to the level of industrialization of the Soviet Union and the USA (Li and Yang, 2005). Available resources were diverted from the agriculture sector to the manufacturing sector, and the central government sharply increased grain procurement from the rural population for urbanization and export (Lin and Yang, 2000). The excess procurement of grain from rural areas, exacerbated by a series

¹Animal studies are also in line with our finding. For example, previous lab experiments on rodents show that decedents of undernourished mother rats tend to have fewer brain cells than decedents of normally nourished mother rats (Strauss, 1997).

of severe weather conditions, led to a huge decrease in caloric intake of rural residents and thus reduced their physical capacity to engage in farm work (Li and Yang, 2005). As a result, grain production dropped substantially, leading to a vicious cycle of malnutrition, lowered labor productivity, and further reductions in output of agricultural products worsened by reduced production incentives (Li and Yang, 2005; Meng and Qian, 2009).

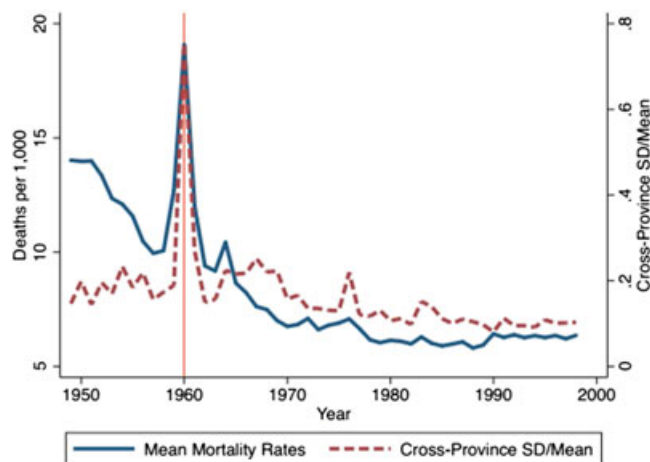
Compared with the pre-famine production level, national grain output dropped by almost 30% in 1960 (Li and Yang, 2005). Exacerbating the impact of lower agricultural production, the Chinese central government's delayed response to the food shortage, severe limitations on interregional transfer of grain and other foods, transfer of food to the industrial sector's workers, and ignorance of local conditions (due in part to politically motivated over-reporting of grain output) all contributed to turning the overall reduction in food availability into probably the worst famine in human history as measured by excess deaths. Scholars estimate that the China Famine resulted in approximately 23–30 million deaths above what might have been expected under normal grain production and distribution and 30 million lost births (Chen and Zhou, 2007).

Although the China Famine was a national phenomenon, the famine intensity varied significantly across provinces (Chen and Zhou, 2007). For example, central provinces such as Henan, Anhui, and Sichuan were severely affected by the famine, but the northeastern provinces were less severely impacted (Almond *et al.*, 2010). Figure 1 shows the annual death rates during the famine period and its geographical variation.

The Chinese central government eventually recognized the severity of the famine and moderated its policies, reducing the transfer of grain from rural areas to urban areas and sending millions of people back to the countryside to boost agricultural production, raising the rural labor force by more than 50 million (Li and Yang, 2005). By 1961, death rates began to come back to the pre-1959 level in over half of the provinces, and birth rates started to rebound as shown in Figure 2.

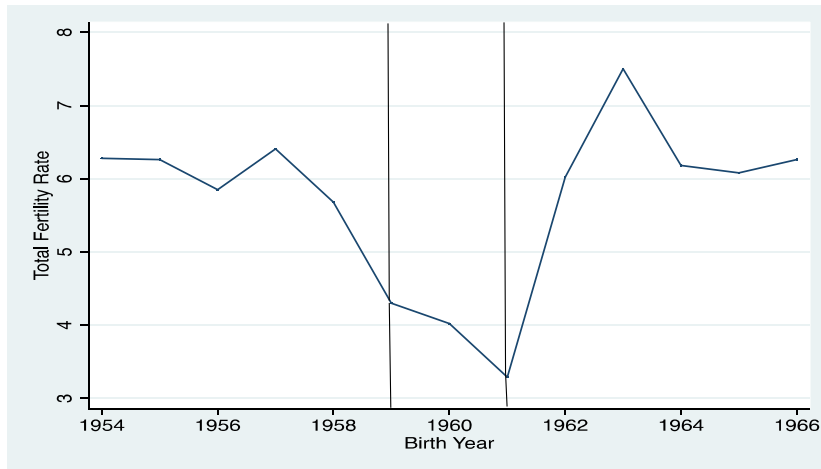
2.2. Related literature

Most existing studies of the lasting impacts of the China Famine have focused on economic outcomes such as labor supply, income, or education attainment (Meng and Qian, 2009; Chen and Zhou, 2007; Shi, 2011; Almond *et al.*, 2010; Kim *et al.*, 2014). Using the 2000 China Population Census Data, Almond *et al.* (2010) show that individuals who experienced the famine *in utero* are more likely to be illiterate, less likely to work, and less likely to get married. Existing research has also found that the famine's impacts are not limited to the first generation. Children who were born to famine survivors tend to have fewer years of schooling, higher BMI, and stunted heights (Fung and Ha, 2010; Kim *et al.*, 2014; Tan *et al.*, 2014).



Source: Meng, Qian and Yared (2014)

Figure 1. Severity and geographical variation of annual death rates in China. Source: Meng *et al.* (2014)



Source: China National Bureau of Statistics

Figure 2. China's total fertility rate, 1954–1966. Source: China National Bureau of Statistics

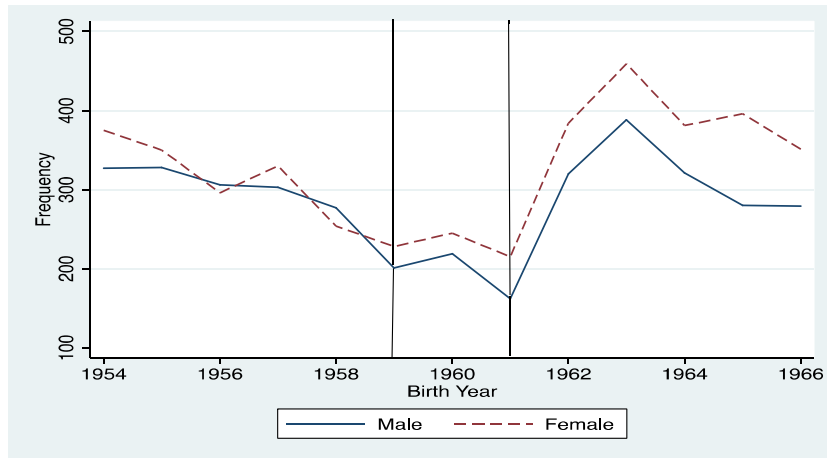
Studies regarding the China Famine's impacts on health outcomes are relatively limited because of the availability of the data. Only simple health measures such as height, weight, and BMI were examined at relatively young ages (20s to 30s) (Chen and Zhou, 2007; Meng and Qian, 2009; Fung and Ha, 2010). It was shown that fetal exposure to malnutrition is associated with significant reduction of height and body weight (Chen and Zhou, 2007; Meng and Qian, 2009). Although height and weight are indicators of famine survivors' health conditions, they provide very rough indicators of the famine's influences on detailed health outcomes such as hypertension, cognitive abilities, mental functions, and other specific health conditions. Our study of the China Famine is an effort to fill the gap by examining a rich set of health outcomes and providing evidence of fetal malnutrition's long-lasting impacts in famine survivors' middle age.

Particularly for mental health, previous studies of the China Famine have focused mainly on fetal malnutrition's impacts on the probability of developing schizophrenia (Clair *et al.*, 2005; Xu *et al.*, 2009). Consistent with the Dutch Famine studies, exposure to malnutrition *in utero* is associated with higher risk of schizophrenia in survivors' early adulthood. However, the data for these studies tend to be restricted to narrow geographical areas. For example, Clair *et al.* (2005) and Xu *et al.* (2009) use local hospital records from Anhui and Guangxi autonomous region and thus cannot control for region-specific heterogeneity.

Our paper closely follows Almond *et al.* (2010) and Kim *et al.* (2014) in terms of the measurement of famine intensity and the identification strategy to estimate the long-term effect of fetal malnutrition experience. Both Almond *et al.* (2010) and Kim *et al.* (2014) use data from the 2000 China Population Census microdata, which provide limited information regarding individuals' health. Therefore, these two papers studied outcomes other than health indicators. Almond *et al.* (2010) mainly focus on the socioeconomic outcomes of the famine survivors, and Kim *et al.* (2014) look at the education outcomes of children of the famine survivors. Using the 2013 wave of CHARLS, our paper contributes to the literature by examining the impacts of the China Famine on survivors' health outcomes in middle age.

3. DATA

The CHARLS is a biannual longitudinal survey that collects rich information on economic, health, and social conditions for a representative sample of individuals in China who were 45 and over in 2011. CHARLS covers 150 counties in 28 provinces, and the sample size of the baseline survey is 17,692 individuals (8471 men and



Source: Authors' calculation

Figure 3. Frequency of sample birth cohorts. Source: Authors' calculation

9221 women) in 10,257 households.² The first baseline survey was conducted in 2011–2012 and the second one in 2013. In our study, we only use the second wave collected in 2013.

The advantages of using data from CHARLS for our research are that (i) it provides a wide array of measures of health and other individual and family characteristics; (ii) it focuses on the middle-age and older population, thus providing an adequate sample to study long-term health effects; and (iii) it contains the individuals' province of birth information. By comparison, the China Population Census would be the best available data in terms of sample size, but the Census asks for very little information on health (a single question on self-reported health status). The China Health and Nutrition Survey contains comparable information, but its effective sample size for our research is significantly smaller than that of CHARLS, because it surveys only nine provinces and covers all age ranges.³

We construct our sample using the following criteria. First, to include substantial time variation in our measure of *in utero* nutrition, we select those who were born from 1954 to 1966, 5 years before and after the China Famine. Second, we restrict the sample to those born in rural areas because the famine took place mostly in the rural areas. We drop individuals from the provinces where provincial death data are not available.⁴

Figure 3 shows that the size of the cohorts between 1959 and 1961 is much smaller than before or after this period, reflecting the increased death rate and the lowered birth rate resulting from the famine severity. We observe a continuing drop in the number of sample individuals starting in 1958 and then a sharp rebound after 1961. This pattern closely mirrors the distributions in birth and death rates in China from 1954 to 1966.

The specific definition of the health and cognitive ability variables we use are provided as follows:

1. 'Speech impediment' is a binary indicator of self-reported disability in speaking. CHARLS asks whether a respondent has any speech impediment. Answering 'yes' to the question would be recorded as 1 (i.e., having a speech impediment) or 0 otherwise.

²Tibet is excluded from sampling.

³In addition, CHNS does not track survey participants who migrate out of the province of the initial interview, so it can potentially create a sample selection bias due to the different likelihood of migration by ability and health.

⁴Chongqing was previously a part of Sichuan but became a direct-controlled municipality in 1997. Therefore, there are no separate provincial death data for Chongqing. In the Supporting Information, we report the regression results including those who report Chongqing as their birth province by considering their birth province as Sichuan. Our results remain robust.

2. ‘Difficulty in walking’ is a binary indicator of self-reported physical disability in walking. CHARLS asks whether a respondent has any difficulty in walking 100 m. Answering ‘yes’ to the question would be recorded as 1 (i.e., having difficulty in walking) or 0 otherwise.
3. ‘Vision disability’ is a binary indicator of self-reported disability in vision. CHARLS asks the individuals to report whether they have any disabilities in vision. Responding yes to the question would be coded as 1 (i.e., having vision disability) or 0 otherwise.
4. We also use a binary indicator of whether a respondent previously had a stroke diagnosed by a doctor. If the respondent answers yes, it is coded as 1 (i.e., had a stroke before) or 0 otherwise.
5. ‘Calculation error’ is a binary indicator of a respondent’s cognitive ability. CHARLS asks respondents to perform a simple arithmetic calculation task (subtracting 7 from 100 consecutively for five times). If a respondent makes an error, calculation error would be coded as 1 (and 0 otherwise).
6. ‘Recall error’ is a binary indicator of a respondent’s ability to recall the date. CHARLS asks respondents to recall the date of yesterday (month and day). If a respondent answers either day or month of yesterday wrong, recall error would be coded as 1 (and 0 otherwise).

Sample statistics are reported in Table I. The final sample size after imposing the aforementioned selection criteria is 7439; 53% of the sample is female, and 94% of the sample is married. The education level of the sample individuals is much higher than that of their parents: More than 65% of the sample completed primary school, while only 50% of their fathers and 18% of their mothers reached this level. The surveyed households on average have 3.45 family members.

We define total annual working hours as the sum of hours spent on farm work, household agricultural work, non-farm employed and self-employed work and unpaid family business, and other side jobs in the past year. There is wide dispersion in the distribution of annual income and working hours. The mean of annual income is 8183 yuan with a standard deviation of 21,561. The mean of the annual working hours is 363 with a standard deviation of 367. There are in total 1740 individuals reporting zero annual working hours, accounting for 23.4% of the total sample. The details of how we construct total annual working hours are described in the Supporting Information.

The mean of the weighted death rate (WDR) is 12.22 per 1000 persons with a standard deviation of 5.48. One standard deviation of the WDR is slightly smaller than the difference of average WDR between famine

Table I. Summary statistics

Variable	Observations	Statistics	
		Mean	SD
Proportion married	7439	0.94	(0.23)
Annual working hours	7376	363	(367)
Proportion of individuals reporting zero annual working hours	7439	0.234	(0.423)
Proportion of the sample individual’s father completed primary school	7439	0.50	(0.50)
Proportion of the sample individual’s mother completed primary school	7439	0.18	(39)
Proportion of women	7439	0.53	(0.50)
Proportion of the sample individual completed primary school	7439	0.65	(0.48)
Family size	7439	3.45	(1.60)
Annual income (in 2013 CNY)	7376	8,183	(21,561)
Weighted death rate (WDR)	7439	12.22	(5.48)
Health outcome variables			
Speech impediment	7392	0.0073	(0.085)
Difficulty in walking	7272	0.0501	(0.22)
Vision disability	7391	0.0591	(0.24)
Ever had stroke	7087	0.0131	(0.11)
Calculation error	7393	0.429	(0.50)
Recall error	7393	0.578	(0.49)

CNY, Chinese Yuan.

years (1959–1961) and non-famine years, which is 6.14. For physical disability measures, (i) 0.73% of the sample has a speech impediment; (ii) 5.91% of the respondents report vision disability; and (iii) 5.01% experienced difficulty in walking. Of the sample, 1.31% reports that they ever had a stroke. The size of the sample with cognitive problems is much larger: 42.9% of the sample made mistakes in carrying out simple arithmetic tasks, and 57.8% of the respondents recall the date incorrectly.

4. ECONOMETRIC SPECIFICATION AND EMPIRICAL STRATEGY

Our econometric model is represented by the following equation:

$$Y_{iptk} = \beta \text{WDR}_{ptk} + \gamma X_i + \mu_p + \delta_t + \phi_k + \varepsilon_{iptk} \quad (1)$$

where the subscript i represents an individual, p a birth province, t a birth year, and k a birth month. We use the province-year level death rate weighted by months *in utero* during birth year t and year $t-1$ as a measure of fetal exposure to malnutrition, following Almond *et al.* (2010) and Kim *et al.* (2014).⁵ For example, an individual born in January 1960 in Shandong would be assigned 1/9th of Shandong’s 1960s average death rate (ADR) and 8/9th of Shandong’s 1959s ADR; for individuals born in September to December, the WDR is the same as the birth year’s ADR, because conception occurred in the year of birth. It follows that for those born in the months January through August, that is, $k=1, \dots, 8$,

$$\text{WDR}_{ptk} = \frac{k}{9} \times \text{ADR}_{pt} + \frac{9-k}{9} \times \text{ADR}_{p,t-1} \quad (2)$$

where ADR is the province-specific and year-specific measure of famine intensity, equivalent to the number of deaths per 1000 individuals in year t and province p . X , a vector of controls, includes other characteristics that might affect current health outcomes such as gender and parents’ education. In the regression, we control for permanent unobserved province-specific heterogeneity, μ_p , year-specific unobserved heterogeneity invariant across provinces, δ_t , and month-specific unobserved heterogeneity, ϕ_k . In the absence of confounding factors, β can be interpreted as the estimated causal effect of fetal exposure to the China Famine on health outcomes.⁶

The following discussion deals with potential confounding factors that would lead to biased estimation of β .⁷

4.1. Selective mortality

The most severely impacted individuals are more likely to have died during or shortly after the famine. Also, because the China Famine took place over half a century ago, those severely impacted individuals who managed to survive birth and early life are less likely to have survived into middle age. As a result, the famine survivors in our sample would be, in general, healthier than the famine victims who are missing because of selective deaths. We do not have any information about those who are missing because of the famine-caused deaths, so we cannot correct for this bias. However, because selective mortality makes our estimates biased

⁵Alternatively, one can use a county-specific measure of famine intensity (Meng and Qian, 2009), but CHALRS does not allow researchers to have access to the county information.

⁶Young children could also have been affected by the famine. For example, our sample individuals born before the famine experienced malnutrition during the infancy period, but our measure of *in utero* famine intensity does not capture such early childhood experience. To the extent early infancy famine experience also negatively affects the health of adults, our comparison group may lead us to underestimate the magnitude of *in utero* effects compared with a population totally unaffected by *in utero* or early-childhood malnutrition. We do not jointly estimate the *in utero* famine experience and the early infancy famine experience because those two measures are correlated that the resulting multicollinearity reduces the statistical power available to test the Barker hypothesis. Because our primary goal is to precisely estimate the fetal impacts, we decided to focus on *in utero* exposure to malnutrition.

⁷The discussion of econometric issues in estimating the long-run health impacts of early-life malnutrition is largely taken from Almond *et al.* (2010) and Kim *et al.* (2014).

toward zero, our estimates of the long-run health impacts of the fetal experience to the China Famine can be interpreted as the lower bounds of the true effects.

4.2. Selective fertility

Because of the extreme adverse environmental and nutritional conditions during the China Famine, marriages and childbearing were postponed or foregone through choice and reduced chance of conceiving (Almond *et al.*, 2010; Chen and Zhou, 2007). Shi (2011) reports that there were about 15 million lost births because of the China Famine. Therefore, children born during the famine would have come from families with better socio-economic and nutritional conditions. Similar to the bias caused by selective mortality, selective fertility during the famine period biases against rejecting the null of no impact of fetal exposure to the China Famine.

Moreover, parents whose childbearing were delayed by the famine appear to have offset the birth-rate dip after the famine ended. Figure 2 reveals a sharp increase in birth rates in 1962, the year after the famine ended. To the extent that the post-famine surge in birth rates is attributable to women whose health was impaired by the famine, it is likely that children born right after the famine inherited characteristics attributable to the famine. Thus, the two fertility selections (positive selection toward less-impacted parents during the famine and negative selection right after the famine) would bias our estimates against rejecting the null of no *in utero* impacts of the China Famine on long-run health outcomes.

4.3. Selective migration

The intensity of the China Famine varied greatly across provinces. Central provinces were the worst hit, while northeastern provinces were relatively spared (Almond *et al.*, 2010). Migration from severely impacted areas to less-impacted regions was virtually prohibited before 1978. According to Chen and Zhou (2007), interprovincial migration accounted for only 0.3–0.7% of the population at risk between 1959 and 1963.

4.4. Measurement error

We acknowledge that WDR is not a perfect measure of fetal malnutrition. A pregnant woman's caloric intake would be a much better measure, but such information is not available. Thus, we argue that WDR is the best available source of information on fetal malnutrition shock during the China Famine. Assuming that fetal malnutrition is a stochastic function of WDR, we use WDR as a proxy for the degree of fetal malnutrition.

Formally, we can write that

$$\text{WDR}_{ptk} = \delta \text{Cal}_{ptk} + \omega_{ptk} \quad (3)$$

where *Cal* is the average fetal caloric intake during pregnancy, δ is a proportionality coefficient, and ω is measurement error unobserved to an econometrician. Assuming the presence of classical measurement error, we interpret our estimate of WDR as biased toward zero; thus, we estimate a lower bound of the true famine effect on long-run health outcomes.

4.5. Other omitted variables

One might be concerned that our estimates of the fetal malnutrition impacts are confounded by the 1966–1976 Cultural Revolution's adverse influences. However, the Cultural Revolution was mainly an urban phenomenon, while the China Famine was mainly confined to rural areas. Thus, we believe that we can ignore its impacts in this study.

We control for the local institutional quality differences in policies that contributed to health through a province-fixed effect to the extent that such institutional differences are time invariant. Differences across provinces in policies adopted after the China Famine could lead to biased estimation, and the direction of the bias

Table II. Probit regression results

	(1)	(2)	(3)	(4)	(5)	(6)
	Speech impediment	Difficulty in walking	Vision disability	Calculation error	Recall error	Had stroke
WDR * 1000	0.208** (0.084) [0.0017]	1.20** (0.507) [0.008]	0.438** (0.196) [0.003]	2.99*** (1.28) [0.016]	2.34** (1.08) [0.013]	0.419* (0.229) [0.003]
Female	-0.0014 (0.0013)	0.029*** (0.005)	0.004 (0.005)	0.015*** (0.014)	0.024* (0.013)	0.0003 (0.003)
Pseudo- R^2	0.065	0.050	0.072	0.040	0.016	0.061
Observations	6878	7089	7227	7228	7228	6852

We estimate the probit model, and the estimated coefficients represent the marginal effects of the independent variables evaluated at the mean on the outcome variables. The effects of one standard deviation increase in weighted death rate (WDR) on the probability of outcome variables are reported in square brackets.

Standard errors clustered at provincial level are reported in parentheses. All regression results include fixed effects for birth year, birth month, birth province, and father's and mother's education.

*** $p < 0.01$;

** $p < 0.05$;

* $p < 0.1$.

would depend on the nature of such differential policy responses, if any. We are not aware of systematically different post-famine policy changes across provinces (Meng and Qian, 2009).

5. RESULTS

Table II presents our estimation results. Standard errors are clustered at the province level and reported in parentheses. Note that all specifications include the father's and mother's education and fixed effects for birth year, birth month, and birth province. We also include a female dummy variable to account for potential gender differences.⁸ As discussed in the previous section, we interpret the estimated coefficient of WDR as a lower bound of the magnitude of the negative long-term health effects of fetal malnutrition. The coefficients reported in Table II represent the marginal effect of a unit change in WDR * 1000 on the probability of a corresponding dependent variable of interest evaluated at the mean of WDR.⁹ In order to show economic significance of the famine impact, we also report the effect of one standard deviation of WDR on the probability of a corresponding dependent variable in square brackets.

5.1. Regression results

As hypothesized, *in utero* exposure to the China Famine has had large and long-lasting impacts on survivors' physical health and cognitive abilities. Column (1) of Table II shows that a one standard deviation increase in famine intensity resulted in a 0.17 percentage-point increase in the probability of a speech impediment, which is a 23.3% increase in the likelihood of suffering from this disability compared with the average individual.

Column (2) reports the famine impact on respondents' evaluations of whether they have any trouble walking farther than 100 m. A one standard deviation increase in famine intensity is associated with a 0.8 percentage-point increase in the probability of difficulty of walking, or about 16% increase in the likelihood of experiencing this disability compared with the average.

⁸In the Supporting Information, we report the regression results of the subsample analysis separately by men and women.

⁹Sample size varies across different outcome variables because of the missing values in the corresponding outcome variables. However, our results are robust even if we use the identical sample across different outcome variables (i.e., the sample without missing values for all outcome variables).

Column (3) further confirms the causal relationship between fetal exposure to famine and physical disability: a one standard deviation increase in famine intensity increases the probability of developing vision disabilities by a 0.3 percentage-point increase, a 5.1% increase in the likelihood compared with the average individual. Disabilities in speech, vision, and difficulty in walking cannot only be viewed as direct health consequences of prenatal exposure to malnutrition but also as complications of other health problems such as stroke. Therefore, we could interpret the results of columns (1) to (3) as reflections of adverse impacts of fetal exposure to malnutrition on survivors' general physical health.

It has been reported that prenatal exposure to malnutrition negatively impacts survivors' cognitive abilities (Barker, 1990). Thus, we examine the relationship between fetal malnutrition and cognition outcomes. In CHARLS, respondents were asked to perform a series of simple arithmetic calculation tests and a date check test. Defining a failure to satisfy either of these tasks as an error, we show in column (4) that a one standard deviation increase in famine intensity resulted in a 1.6 percentage-point increase in the probability of calculation error, which is a 3.7% increase in the likelihood of error in the calculation test; in column (5), we see that a standard deviation increase in WDR leads to a 1.3 percentage-point increase in the probability of not knowing the correct survey date, which is a 2.2% increase in the likelihood of recall error. Interestingly, coefficient estimates on the female dummy are significant for both measures indicating a potential gender difference in impacts from fetal exposure to famine on cognitive functions.

Column (6) reports estimation results for the impact of *in utero* famine exposure on the probability of having suffered from a stroke. We see that a one standard deviation increase in famine intensity would lead to a 0.3 percentage-point increase in the probability of having had stroke, which amounts to a 22.9% increment of risk compared with the mean. This finding shows significant influences of adverse prenatal environment on survivors' cerebrovascular health.

Our results confirm many findings of the previous literature regarding the damaging effects of *in utero* exposure to malnutrition. However, we do not find substantial impact of famine on health measures commonly used in the China Famine literature such as height and weight as reported by Chen and Zhou (2007) as well as Meng and Qian (2009).¹⁰ Neither do we find any statistically significant results for other ailments such as heart attack although many coefficients have the expected signs. Because our sample individuals have only reached their middle ages, we might expect to observe more precisely estimated impacts on the aforementioned health problems as they grow older.

5.2. Additional analysis

Fetal exposure to malnutrition could have impacted survivors through various pathways. For example, other than directly influencing survivors' health through fetal exposure to malnutrition, famine could also impact the later-life outcomes through education. To examine whether education is a potential pathway to the observed health impacts of the famine, we include the sample individual's own education attainment as an additional control in the baseline specification. The regression results are reported in Table III. We acknowledge that education attainment can be partially determined by the famine exposure, and thus, it might not be an ideal control variable (the so-called *Bad Control problem* discussed in Angrist and Pischke (2009)). Thus, we interpret the findings in this analysis as suggestive only at this point.

¹⁰We conjecture that the following reasons can explain the difference between our results and the findings of Chen and Zhou (2007) as well as Meng and Qian (2009) regarding height and weight. First, we use CHARLS, a nationally representative survey of individuals over age 45, while the other two studies use CHNS, which surveys only nine provinces and does not keep track of respondents who move out of the survey provinces. Therefore, our sample is much bigger in size and more representative. Second, the eligible sample size of CHNS as opposed to CHARLS is much smaller. Third, we use the survey conducted in 2013, while Chen and Zhou (2007) and Meng and Qian (2009) use the CHNS survey conducted in 1991 and 1989, respectively. Therefore, the famine effect on height and weight in relatively young ages could have become smaller because of age-related factors such as height shrinkage at old age as documented in Huang *et al.* (2013).

Table III. Robustness analysis: inclusion of the respondents' own education as a control

	(1)	(2)	(3)	(4)	(5)	(6)
	Speech impediment	Difficulty in walking	Vision disability	Calculation error	Recall error	Had stroke
WDR * 1000	0.141** (0.056)	1.16** (0.526)	0.381* (0.200)	2.73* (1.64)	1.93* (1.01)	0.398* (0.213)
Primary school	-0.0045*** (0.001)	-0.0219*** (0.004)	-0.0892 (0.007)	-0.300*** (0.024)	-0.251*** (0.016)	-0.002 (0.002)
Middle school	-0.0067*** (0.001)	-0.0212*** (0.005)	-0.021*** (0.005)	-0.428*** (0.0202)	-0.331*** (0.133)	-0.007*** (0.003)
Above middle school	-0.0045*** (0.0007)	-0.0277*** (0.005)	-0.035*** (0.005)	-0.521*** (0.018)	-0.342*** (0.012)	-0.0015 (0.003)
Female	-0.003** (0.001)	0.022*** (0.005)	-0.004 (0.005)	0.057*** (0.014)	0.057*** (0.011)	-0.0005 (0.003)
Pseudo- R^2	0.133	0.06	0.081	0.12	0.069	0.067
Observations	6878	7089	7227	7228	7228	6852

We estimate the probit model, and the estimated coefficients represent the marginal effects of the independent variables evaluated at the mean on the outcome variables. Standard errors clustered at provincial level are reported in parentheses. All regression results include fixed effects for birth year, birth month, birth province, and father's and mother's education.

*** $p < 0.01$;

** $p < 0.05$;

* $p < 0.1$.

Table IV. Robustness analysis: impacts of WDR on education attainment

	(1)	(2)	(3)	(4)
	Graduated from primary school	Graduated from middle school	Graduated from high school	Years of completed education
WDR * 1000	-0.232 (1.15)	0.582 (1.40)	-0.366 (0.855)	-0.443 (14.3)
Female	0.026 (0.022)	-0.120*** (0.013)	-0.103*** (0.008)	-2.87*** (0.162)
(Pseudo-) R^2	0.041	0.060	0.107	0.212
Observations	7272	7272	7272	7272

WDR, weighted death rate.

We estimate the probit model in columns (1) to (3) and the ordinary least squares model in column (4). The estimated coefficients represent the marginal effects of the independent variables evaluated at the mean on the outcome variables.

Standard errors clustered at provincial level are reported in parentheses. All regression results include fixed effects for birth year, birth month, birth province, and father's and mother's education.

*** $p < 0.01$;

** $p < 0.05$;

* $p < 0.1$.

After controlling for education attainment, we find that the coefficient estimates of WDR become somewhat smaller, suggesting that the negative long-term famine impacts can be partially explained by the education channel. The coefficient estimates on the education dummies also show that education and health are positively correlated, which is consistent with the existing literature.

To further examine the role of education on the health impacts of the famine, we check whether the famine exposure leads to lower education attainment by regressing different measures of education outcomes on WDR. The probit regression results on binary indicators of whether a respondent has graduated from a primary school, middle school, and high school, respectively, and the ordinary least squares regression result on the years of completed schooling are reported in Table IV. In general, our findings show that fetal malnutrition exposure has negative impacts on an individual's education attainment (except for the middle school graduation) although the coefficient estimates are not precise.¹¹ Thus, we argue that it is highly probable that the famine exposure has an indirect impact on health via the education channel.

In addition, we conduct various robustness checks. First, we estimate the linear model using the ordinary least squares method because our baseline specification is a non-linear probit model. Second, we estimate the baseline specification with the ADR, instead of the WDR. Third, we run the same set of regression on the urban-born population. Fourth, to explore the gender differences in the China Famine's impacts on survivors' health outcomes, we divide the sample into male and female subsamples and run the baseline probit regression on each subsample. Last, we construct two additional measures of recall error: whether a respondent can correctly recall the current season (Spring, Summer, Autumn, and Winter) at the time of interview and whether self-evaluated memory is bad or not. We then run the same baseline regression on these two variables. We report and discuss the regression results of each of the aforementioned robustness checks in the Supporting Information.¹²

¹¹Female respondents have significantly lower levels of education compared with male respondents. This finding is not surprising when considering China's son preference, especially in rural areas.

¹²The regression results using ordinary least squares are in general similar to the baseline results except that the coefficient estimate of the probability of stroke becomes less statistically significant. However, the magnitude is comparable with the baseline probit result. Regression results using the ADR are robust to the modification of the measure of malnutrition exposure. We also run the same set of regression on urban-born population and find the results opposite of prediction. Because the sample size is much smaller, the estimated results may suffer from reduced power and measurement errors.

6. CONCLUSION

We report evidence of long-term adverse health impacts of fetal malnutrition based on survivors in their 50s who were born during the 1959–1961 China Famine. Our results support the Fetal Origins Hypothesis (Barker, 1990) that *in utero* shocks can alter the activities of the epigenome¹³ in favor of survival, but only at the cost of a higher probability of developing certain diseases in later life stages. We find that fetal exposure to malnutrition has large and long-lasting impacts on both physical health and cognitive abilities, including the risks of suffering from a stroke, physical disabilities in speech, walking and vision, and measures of mental acuity. Our findings on the health impacts of fetal malnutrition on middle-age survivors suggest that it should be desirable to trace the changes of health status of the famine survivors as they age into later life stages.

Our study provides evidence supporting policies and programs to improve the nutritional status of pregnant women. As implied by one of the United Nations' Millennium Development Goals, maternal health has received increasing attention in recent years. For example, Improving Nutrition and Food Safety for China's Most Vulnerable Women and Children, a joint program by the United Nations and the Chinese central and local governments, has focused on food-related issues of 1.2 million children, women of childbearing age, and other at risk populations. It aims to reduce mortality and other adverse impacts of malnutrition by providing nutritional packages to children and pregnant women (Chen, 2013). Our findings imply that the payoffs to such interventions play out much further into the future than evaluation of their immediate benefits might suggest.

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¹³Epigenome can be viewed 'a series of switches that cause various parts of the genome to be expressed or not' (Almond and Currie, 2011).

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SUPPORTING INFORMATION

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