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## Article

Early-life exposure to weather shocks and child height: Evidence from industrializing Japan<sup>☆</sup>Kota Ogasawara<sup>a,\*</sup>, Minami Yumitori<sup>b</sup><sup>a</sup> Graduate School of Social Sciences, Chiba University, 1-33, Yayoicho, Inage-ku, Chiba 263-8522, Japan<sup>b</sup> Department of Industrial Engineering and Economics, Tokyo Institute of Technology, 2-12-1, Ookayama, Meguro-ku, Tokyo 152-8552, Japan

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## ABSTRACT

In this study, we estimate the long-run effects of early-life exposure to weather shocks on the height of primary school children. To estimate the global impacts on almost the entire child population in an industrializing country, we utilize both a unique nationwide multi-dimensional longitudinal dataset of Japanese children aged 6–11 and official monthly statistics on meteorological conditions in the 1920s. We observe that the exposure to cold waves in early-life exerted stunting effects on both the boys and girls. In the coldest regions in the northeastern area of Japan, the stunting effects of cold weather shocks on the boys and girls are estimated to be approximately 0.8 and 0.6 cm, respectively. Our observation indicates that prenatal (postnatal) exposure is important for the boys (girls). Our results suggest that the marginal effects of cold waves are stronger in the warmer regions than in the colder regions.

## 1. Introduction

Stunting during childhood induced by early-childhood exposure to ambient stress can be associated with future negative health outcomes and lower cognitive skills (Kelly, 2011; Rosales-Rueda and Triyana, 2018). Because stunting can cause impairments to the brain cells (Victoria, Adair, and Fall, 2008), stunted growth has also been associated with negative later-life socioeconomic outcomes (McGovern, Krishna, Aguayo, and Subramanian, 2017). Accordingly, overcoming stunting is one of the most important policy issues in developing countries (Oruamab, 2015; de Onis and Branca, 2016).

Early-life shocks exert lasting adverse effects on human capital formation (Barker and Osmond, 1986; Heckman, 2007; Almond and Currie, 2011a, 2011b). An increasing amount of literature has demonstrated causal relationships between a wide variety of exogenous shocks, which include epidemics, famine, terrorism attack, and wars, and human health (Almond, 2006; Almond, Edlund, Li, and Zhang, 2010; Harville, Xiong, and Buekens, 2010; Lee, 2014). A recently expanding avenue in related literature focuses on the relationships between climatic conditions and infant health (Deschênes, 2014). Extreme

weather events such as heat and cold waves lead to trade-off issues between fuel and food expenditures, which can cause the under-nutrition of the fetus (Bhattacharya, DeLeire, Haider, and Currie, 2003). These natural disasters can also be correlated with substantial mental stress among pregnant mothers (Torche, 2011). A pioneering study by Deschênes, Greenstone, and Guryan (2009) demonstrated that fetal exposure to heat and cold waves was associated with lower birth weight in the U.S. during the 1970s and 1980s. Similar relationships between weather shocks and adverse birth outcomes have been widely observed in cross-country studies, particularly those focused on developing countries (Currie and Rossin-Slater, 2013; Grace, Davenport, Hanson, Funk, and Shukla, 2015; Andalón, Azevedo, Rodriguez-Castelán, Sanfelice, and Valderrama-González, 2016; Molina and Saldarriaga, 2017; Zhang, Yu, and Wang, 2017).

The present study analyzes the persisting effects of early-life exposure to weather shocks on child height in industrializing Japan. While literature has focused on birth outcomes as described, the long-term consequences of weather shocks on children has been understudied. A few remarkable studies have investigated the present relationship between climatic conditions and child height in the

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developing countries. Skoufias and Vinha (2012) observed that the negative temperature and positive rainfall shocks in prior seasons have exerted stunting effects on children between 12 and 47 months of age in Mexico in 2000. Rabassa, Skoufias, and Jacoby (2014) found similar stunting effects of rainfall shocks on children between 0 and 35 months of age in Nigeria. Groppo and Kraehnert (2016) demonstrated the stunting effects of exposure to cold winter in utero on the height of children younger than 7 y in Mongolia in 2012–13. Mulmi, Block, Shively, and Masters (2016) also observed that the higher vegetation experienced in utero is associated with the larger height of children aged 12–59 months in Nepal in 2006 and 2011.

Considering these backgrounds, the present study would contribute to the related literature in terms of the following two aspects. First, it provides evidence of the long-run effects of weather shocks on child health by using the nationwide panel dataset, which covers almost the entire child population in an industrializing country. Related studies have utilized a variety of household survey datasets, which covers several hundreds to several thousands of households, to investigate the impacts of weather shocks on child height. Analytical results were mainly obtained through cross-sectional regressions using these detailed survey data. By contrast, we have sought to use a comprehensive physical examination of statistics compiled by the Japanese Government in the early 20th century, which covers approximately 95% of the children who were of primary school age between 1928 and 1933, and is less likely to be affected by sample selection bias. In order to more effectively identify the impacts of weather shocks, we applied the bilateral-specific fixed effects models to our three-way tensor data (in unit of prefecture-year-age) to control for unobserved time-varying factors. Secondly, it investigates the long-run effects of weather shocks on primary school children aged 6–11 y in industrializing Japan. While previous studies have focused on the adverse effects of climatic conditions on early childhood (up to 5 y old) as described, we seek to contribute to the literature by analyzing the adverse effects of climatic conditions on middle and later childhood (over 6 y old).

Industrializing Japan is a reasonable study-target in terms of our specific research question. First, we can utilize the high quality official statistics of both biological and meteorological data that have been compiled under the nationwide registration system (Drixler, 2016). An important advantage of using a nationwide dataset is that it substantially reduces potential sample selection biases in child height, which has recently attracted attention in related literature (Bodenhorn, Guinnane, and Mroz, 2017; Schneider 2018). Since our data cover nearly the entire child population at that time, it is highly unlikely that the selection bias in the height will be problematic (Schneider and Ogasawara, 2018). Second, individuals who lived in the early 20th century could not have benefited from risk prevention technologies designed to address weather shocks, such as air conditioners (Barreca, Clay, Deschênes, Greenstone, and Joseph, 2016). Although there has been a significant spike in air conditioner purchases among households in middle-income countries, air conditioning is still uncommon in low-income countries (Davis and Gertler, 2015). For example, less than 10% of the homes in India, Indonesia, and Nigeria had air conditioners in 2012 (JETRO, 2016, p.7). Correspondingly, the cooling demand potential relative to the U.S., where over 90% of the homes have air conditioning, are 1400% in India, 320% in Indonesia, and 190% in Nigeria, respectively (Goetzler, Guernsey, Young, Fuhrman, and Abdelaziz, 2016, p. 8). Third, the public health environments in industrializing Japan were also similar to those of present-day developing countries. The probability of death of 1-year old children in the 1920s was close to the worst of the rates in the developing countries at present (World Health Organization, 2013). Moreover, the mean national height-for-age z-scores of Japanese primary school children in the 1930s was close to the scores in rural areas in low- and middle-income countries today (Paciorek, Stevens, and Finucane, 2013; Ogasawara, 2018a).

We observed that an exposure to cold waves in early-life exerted

stunting effects on both boys and girls. Our result indicates that pre-natal (postnatal) exposure is important for the boys (girls). For the regions with the median length of days exposed to cold waves, our estimates indicate that the boys who were exposed to cold wave while in the womb were shorter by 0.1 cm, whereas the girls who were exposed to cold wave at age two were shorter by 0.05 cm. These effects were more evident in the cold weather regions. In the coldest region in the northeastern part of the Japanese archipelago, where children had experienced 52–64 d of cold waves, the stunting effects on boys and girls reached 0.8 and 0.6 cm, respectively. These magnitudes in the coldest regions are so large as to be associated with the later-life negative health outcomes. We also found that the marginal effects of the cold waves seem to be stronger in the warmer regions than in the colder regions.

The remainder of the paper is structured as follows. Section 2 reviews the incidence of heat and cold waves in prewar Japan and examines the likely channels for the children. Section 3 describes the data used. Section 4 presents our empirical strategies and results. Section 5 presents a discussion.

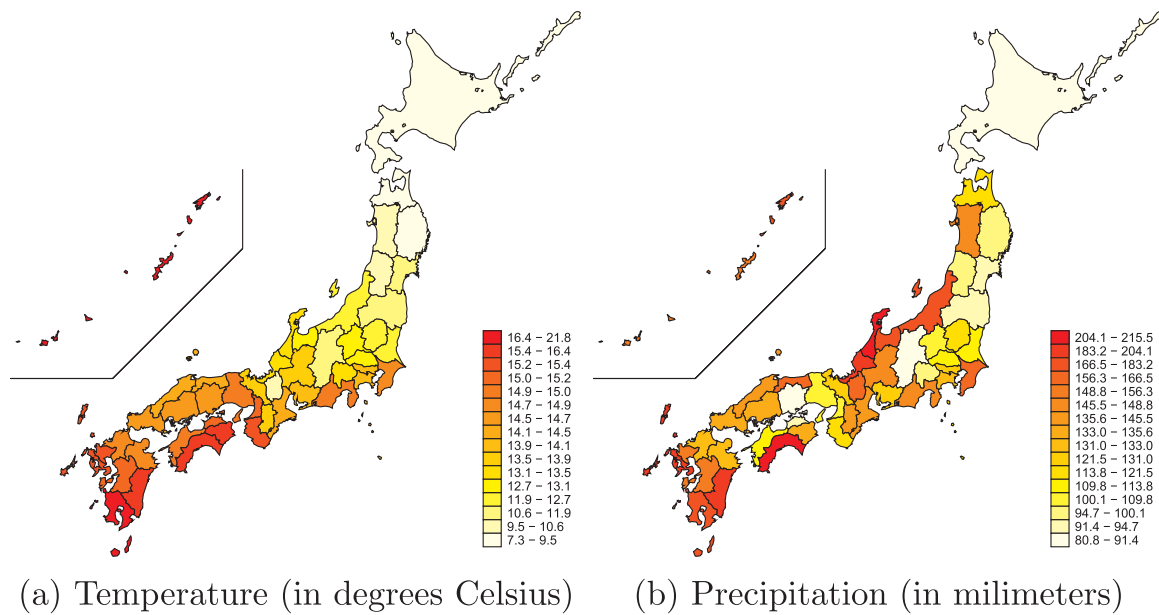
## 2. Background

### 2.1. Regional heterogeneity in weather shocks

The climatic condition of Japan varies considerably as the Japanese archipelago is long from the north to the south and has mountainous area between the Pacific sea and the Sea of Japan sides. The Japanese Meteorological Agency (JMA) summarizes Japan's climate as follows: Northern part with warm summers and cold winters; Eastern part with hot and humid summers and cold winters; Western part with very hot and humid summers and moderate cold winters; Southern part with a subtropical oceanic climate, which has hot and humid summers and mild winters (Appendix B.2). Fig. 1 illustrates such variation in the conditions with respect to the average temperature and precipitation, between 1923 and 1928. The average temperature shown in Fig. 1a exhibits evident gradation from the north to the south and ranges from 7.3 °C to 21.8 °C with a mean value of 13.7 °C. The average precipitation presented in Fig. 1b exhibits a similar albeit more complex pattern because it is more likely to be affected by the mountains. This feature of the spatial distribution indicates that the heat (cold) wave is more likely to be caused in the southern (northern) part of the archipelago.

Fig. 2 illustrates the distributions of the weather shocks. It is noteworthy that even in the early twentieth century, the JMA had reported the information on the number of days with temperature above or below certain thresholds. We then followed the official definitions by the JMA and define the heat and cold wave variables as follows. Fig. 2a presents the variation in heat wave, defined as the annual average number of days on which the minimum temperature exceeds 25 °C. Fig. 2b presents the variation in cold wave, defined as the annual average number of days on which the maximum temperature is below 0 °C. The definitions for heat and cold waves here are the most conservative ones among the JMA data. Thus the probability of occurrence of these weather shocks in a year is approximately 2.1%. As shown in both the figures, while the heat wave is more likely to be caused in the western part and particularly in the southern part with a subtropical oceanic climate, the cold wave tend to occur in the eastern part and particularly in the northern part with very cold climate. This implies that if we take both waves into account, weather shocks can occur in all parts of the archipelago.

Finally, we have verified that the temperature had been stable over the 1920s and thus that there were no specific trend in Japan (A.1). The foregoing discussion indicates that the rich variations in the climatic conditions that we observed would render Japan a preferable object for studying the impacts of weather shocks on human health.



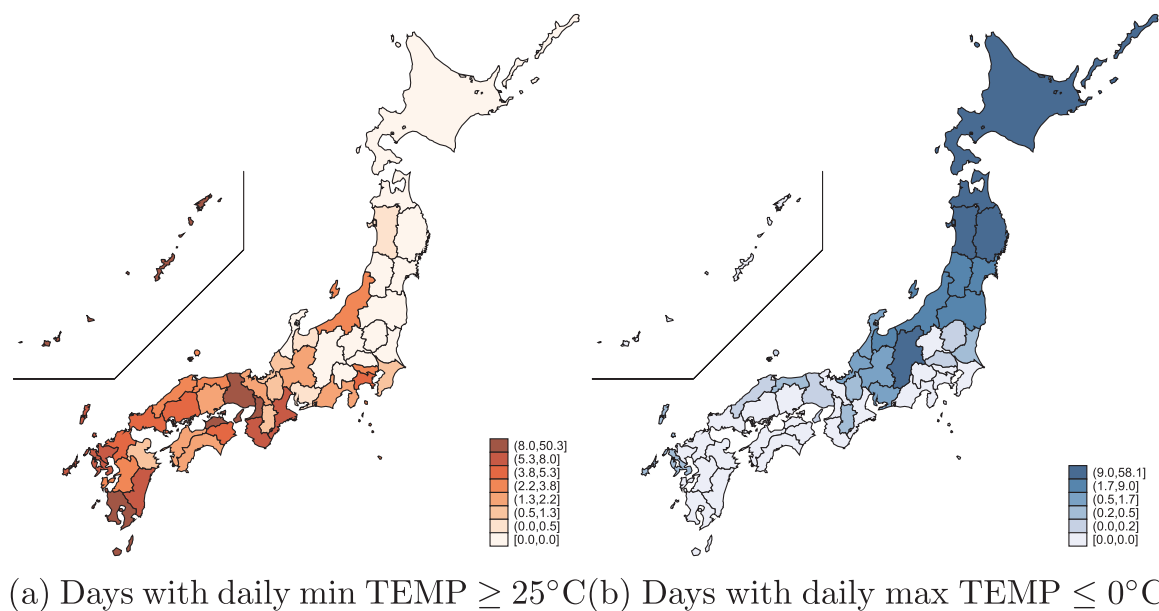
**Fig. 1.** Average monthly temperature and precipitation, Notes: The average monthly temperature (in degree Celsius) and precipitation (in millimeters) between 1923 and 1928 are illustrated in both the figures. Source: Created by the authors from the JMA dataset (see Section 3.2).

2.2. Potential channels

The potential channels linking weather shocks to child stunting can be explained by the following two main reasons. The first channel can be regarded as the direct effects of cold weather shocks—the “heat-or-eat” trade-off. Particularly during cold waves, fuel expenditure increases in response to abnormally cold weather. [Bhattacharya et al. \(2003\)](#) found that poor parents and their children tend to eat less food during cold-weather budgetary shocks (see also [Beatty, Blow, and Crossley, 2014](#)). In the case of Japan, coal stoves began to be used in the larger cities in the late 1920s. However, since these stoves were fueled by coal, the heat-or-eat trade-off became an unavoidable issue ([Matsumoto, 1989](#)). The relationship between lower maternal nutritional intake during pregnancy and lactation to a smaller offspring has

been demonstrated through animal experiments ([Barker, 1992, 1998](#)). As discussed in the introduction, the negative aspects of a lower nutritional intake in utero and during early-childhood because of disasters have also been observed in humans ([Almond and Currie, 2011a; Currie and Vogl, 2013](#)). Considering this evidence, we expect that children who experienced cold waves in their early-childhood were more likely to be shorter than those who had not experienced cold waves during their early childhood.

The second channel is maternal stress. A growing body of literature has found evidence that natural disasters, such as earthquake and hurricanes, can cause substantial mental stress ([Paxson et al., 2012](#)). Prenatal maternal stress caused by disasters increases the risk of adverse pregnancy outcomes, such as a shorter gestational period and low birth weight ([Glynn, Wadhwa, Dunkel-Schetter, Chicz-DeMet, and](#)



**Fig. 2.** Geospatial variations of heat and cold waves, Notes: Heat wave is the annual average number of days on which the minimum temperature exceeds 25 °C. Cold wave is the annual average number of days on which the maximum temperature below 0 °C. The sampled period ranges from 1923 to 1928 Source: Created by the authors from the JMA dataset (see Section 3.2).

**Table 1**  
Descriptive statistics.

	Mean	SD	Min	Max
Dependent and weather shock variables:				
Height of boys (cm)	120.63	8.28	103.90	139.10
Height of girls (cm)	119.73	8.67	102.50	139.50
Heat wave exposure in utero	2.55	6.43	0.00	49.47
Heat wave exposure at age 0	2.72	7.38	0.00	56.00
Heat wave exposure at age 1	2.95	7.69	0.00	56.00
Heat wave exposure at age 2	3.38	8.45	0.00	66.71
Heat wave exposure at age 3	3.65	9.04	0.00	68.00
Heat wave exposure at age 4	3.79	8.92	0.00	68.00
Heat wave exposure at ages 0–4	16.49	40.25	0.00	301.33
Cold wave exposure in utero	2.29	7.62	0.00	51.82
Cold wave exposure at age 0	3.03	9.83	0.00	62.45
Cold wave exposure at age 1	3.04	9.70	0.00	62.45
Cold wave exposure at age 2	3.26	10.05	0.00	63.70
Cold wave exposure at age 3	3.11	9.80	0.00	63.70
Cold wave exposure at age 4	2.98	9.76	0.00	63.70
Cold wave exposure at ages 0–4	15.41	47.24	0.00	271.60
Additional control variables:				
Secondary sex ratio in birth year	1.04	0.02	0.96	1.17
Infant mortality in birth year (%)	145.48	29.08	55.67	231.93
Tuberculosis death rate (%)	1.30	0.28	0.71	2.13
Rice yield per hectare in birth year (liters)	33.65	6.46	6.63	77.15
Soy yield per hectare in birth year (hectoliters)	16.28	3.43	7.14	26.68
Milk production per capita in birth year (liters)	1.65	1.87	0.30	14.51
Share of medical doctors (%)	0.07	0.03	0.02	0.16
Share of midwives (%)	0.06	27.43	0.01	0.12
Share of peasants (%)	27.43	8.19	8.61	52.47
School enrolment rate of parental generation (%)	95.68	2.94	82.87	99.78
Urbanization rate (%)	8.59	15.15	0.00	73.09
Dummy for earthquake cohort	0.02			
Dummy for recession cohorts	0.50			

Notes: The number of observations is 1692 for both the boys and girls subsamples. The definitions of heat and cold waves are described in Section 3.2. The birth years and age ranges are 1923–1928 and 6–11, respectively. Infant mortality is the number of infant deaths per 1000 live births. Tuberculosis death rate is the number of tuberculosis deaths per 1000 people. The school enrolment rate in the parental generation is the primary school enrolment rate observed 15 years before the year of birth. Urbanization rate is percentage of people in cities larger than 100,000. Appendix B describes the details of the documents and definitions.

Sandman, 2001; Hibino et al., 2009; Tan et al., 2009; Torche, 2011). Deschênes et al. (2009) found that fetal exposure to heat and cold waves led to the lower birth weight. Since adverse pregnancy outcomes are associated with stunting, we expected that the potential mental stress induced by weather shocks could also lead to shorter stature among children (Datta Gupta, Deding, and Lausten, 2013).

It should be noted here that it is challenging to completely separate both channels, as is evident from existing literature. Therefore, this study intends to capture the overall effects of the heat and cold waves on the height of children.

However, we intend to separate a few other potential channels. The first channel is damage to agricultural production owing to heat and/or cold waves. In the case of Japan, the relationship between climatic conditions and rice productivity is likely the most important issue, because rice was the dominant staple food at that time (Peng et al., 2004). The second channel is associated with the fact that weather shocks can be correlated with the risk of infectious diseases (Tamerius et al., 2011). Heat and cold waves may increase the likelihood of respiratory diseases and infections in the digestive tract (Ogasawara and Matsushita, 2017). Contracting these acute diseases during pregnancy can cause a substantial decrease in fetal nutritional intake owing to the rejection reactions in mothers, such as high fever, vomiting, diarrhea, and loss of appetite (Metzger, Vileisis, Ravnika, and Freinkel, 1982;

Tomkins, Murray, Rondo, and Filteau, 1994; Kawana et al., 2007).

These potential channels are, however, considered to be less important factors than the heat-or-eat trade-off and maternal stress. In Appendix A.2, we have indeed confirmed that both heat and cold waves are not statistically significantly correlated with agricultural production and cause-specific mortality rates. This result implies that the channel via agricultural production and infectious diseases cannot provide plausible explanations for stunting in children due to weather shocks. Despite this, we included both agricultural variables and a few mortality rates in our empirical analysis to control not only for the direct effects of agricultural production, including macroeconomic price shocks on products, but also for disease environments in the birth year of the children (Section 3.3).

The discussion above summarizes the mechanisms by which early-life exposure to weather shocks affects the health of children. However, it is necessary to account for the fact that the critical period may differ with gender. This is mainly because of a proposition based on the Trivers–Willard theory, which proposes the hypothesis that prenatal shocks reduce the number of boys relative to girls at birth (Trivers and Willard, 1973). A growing body of studies utilizing natural experiments has validated this hypothesis (Charnov et al., 1981; Clutton-Brock, Albon, and Guinness, 1984; Catalano et al., 2005, 2006; Ruckstuhl, Colijn, Amiot, and Vinish, 2010; Bethmann and Kvasnicka, 2014; Bruckner, Helle, Bolund, and Lummaa, 2015; Valente, 2015; Suzuki, Yamagata, Kawado, and Hashimoto, 2016). The results from these studies provide evidence that male fetuses are more vulnerable and thus, unhealthy fetuses are culled in utero before birth, whereas female fetuses are more robust against ambient stressors (Bruckner et al., 2015). In the context of weather shocks, cold weather shocks during gestation are more likely to cull unhealthy males in utero and thus to leave healthy males with longer life spans behind (Catalano, Bruckner, and Smith, 2008). By contrast, the male cohorts who experienced benign temperature during gestation tend to have shorter lifespans (Catalano, Bruckner, and Smith, 2012). In order to control for the potential effects from natural selection before birth, therefore, we will control for the secondary sex ratio, i.e., the sex ratio at birth, in our empirical analysis in Section 4. If the effects of fetal weather shock exposure are still clearer on the boys than on the girls after controlling for the secondary sex ratio, this “culled male” hypothesis may not be valid. However, on average, male infants are still less healthy than their female counterparts because a certain proportion of unhealthy male fetuses had not been culled and survived despite in utero exposure to weather shocks.

### 3. Data

#### 3.1. Biological outcome

We use the height of primary school children as a key outcome variable to contribute to the related literature described in the introduction section. Height reflects accumulated nutritional status and thus is considered to be an appropriate proxy for the early-life environment (Currie and Vogl, 2013). The dataset used in this study comprises data on primary school students aged 6–11 y who were born between 1923 and 1928 in the units of 47 prefectures. The original official statistical reports are the Statistics of School Physical Examination (SSPE), which were published by the Physical Education Bureau, Ministry of Education. As physical examinations are conducted in April of each year for all primary schools (*shōgakkō*), the coverage of our dataset is approximately 95% of the primary-school-aged population (Appendix B.1). As described in the introduction section, an important contribution of this study is its investigation of the effects of weather shocks on a large part of the juvenile population in an industrializing society. The average heights of boys and girls are 120.6 cm and 119.7 cm, respectively (Table 1).

Although the height-for-age z-score of modern WHO standards

(HAZ) is occasionally used to control for the age effects, we do not use the score for our analyses. This is because the differences in the pubertal growth spurt between children in the 20th century and modern healthy children cause a distorted height-for-age profile for our sampled children (Schneider and Ogasawara, 2018). Thus, it can be fundamentally problematic to use the HAZ, which uses historical statistics, for our analysis.

### 3.2. Weather shocks

Heat and cold waves are defined following the official definitions by the JMA, as discussed in Section 2.1. Heat and cold waves can be defined as the annual average number of hot and cold days, respectively. However, several days of high or low temperatures in a row would be a better definition of a heat or cold wave than a definition that simply counts the number of hot or cold days. Accordingly, a heat wave is defined as the annual average number of days on which the minimum temperature exceeds 25 °C for at least for two days, whereas a cold wave is defined as the annual average number of days on which the maximum temperature is below 0 °C for at least two days. Our baseline results remain largely unchanged if we use an alternative definition of these variables that uses three consecutive days instead of two consecutive days, as will be seen in Section 4.

In order to precisely match the monthly weather shock variations to the exposed annual cohort, we first calculated the inverse-distance weighted average of all the valid measurements from three stations in each prefecture following Deschênes et al. (2009). We calculated the weighted average of weather shocks via weighted transformation in the spirit of Almond (2006). Finer details of this transformation is described in Appendix B.2. Table 1 presents the summary statistics for heat and cold waves.

The other potentially important weather shock would be heavy rain, which can disrupt agricultural productivity and is likely to increase the risk of infectious diseases (Lohmann and Lechtenfeld 2015; Groppo and Kraehnert 2016). However, as we discussed in Section 2.1, the spatial distribution of precipitation in Japan exhibits a less clear pattern than that of heat and cold waves. In fact, we confirmed that the effects of heavy rain are negligible in most cases. More detailed results are reported in Appendix C.1. Therefore, we focus on the impacts of the heat and cold waves in our empirical analysis.

We do not prefer to use the z-score for the weather shock variables in our analysis. The main reason is that the z-score is more likely to vary based on the definition of the reference value in our multi-dimensional panel data. For example, the score calculated by using the mean and standard deviation (SD) of the temperature across the measured (or birth) years and the score based on the mean and SD across the prefectures differ significantly. Hence, we prefer to use the externally defined weather shock variables (see Curtis, Smith, Ziganshin, and Eleftheriades, 2016 for the discussion). As we will see, the sensitivity of our definition, i.e., the temperature threshold, is tested in Section 4.4.

### 3.3. Additional control variables

We considered a set of variables to control for the observed characteristics of the prefectures. First, as discussed in Section 2.2, we included the secondary sex ratio, i.e., the ratio of male to female live births, to control for gender differences in fetal vulnerability during gestation. Mortality selection after birth can also cause a positive selection bias on the cohort, as unhealthy children live to adulthood. We used the birth year infant mortality as the mortality selection variable (Almond, 2006; Bozzoli et al., 2009). This variable also controls for potential disease environments, as discussed (Hatton, 2011). We further considered the TB death rate in the birth year to control for the disease environments for parents because TB and typhoid fever were the representative respiratory infectious disease for adults at that time in Japan. However, the typhoid fever death rate was already low in our

study period (Ogasawara and Matsushita, 2018). Second, as discussed in Section 2.2, we included the indices of agricultural productivity to control for the direct effects of agricultural production, including macroeconomic price shocks on products. These variables include the rice yield per hectare in the birth year, soy yield per hectare in the birth year, and milk production per capita in the birth year. Although unobservable soil quality is likely to affect productivity, we consider this by controlling for the prefecture-year-specific fixed effects in our analysis. We also considered the share of medical doctors, midwives, and peasants to control for the socioeconomic conditions and potential wealth level. The primary school enrolment rate in the parental generation is included to capture the socioeconomic background of the parents (Brown, 2011). This school enrolment rate is defined as the enrolment rate observed in the 15 years preceding the birth year. The years of lag are decided based on the mean age at the time of the first marriage of women and men in the interwar period (Appendix B.3) To deal with the urban-rural inequalities in population health, we also included the urbanization rate, i.e., the percentage of people in cities with populations larger than 100,000 (Paciorek et al., 2013). We considered the potential adverse effects of exposure to the Great Kantō Earthquake of 1923 (Hunter, 2014; Ogasawara, 2018b). An indicator variable for the cohort born in the Kantō region in 1923 is used. Finally, we further considered the potential adverse effects of the recession owing to the financial crisis in 1927 (Rockoff and Suto, 2017). An indicator variable that takes the value one for the 1926–28 birth cohorts who were likely to have been affected by the recession owing to the financial crisis around birth is used. Table 1 reports the descriptive statistics for the variables. The finer details of the documents and variable definitions are described in Appendix B.3.

## 4. Empirical analysis

### 4.1. Estimation strategy

In order to identify the effects of fetal exposure to the weather shocks, we utilize the variations in the frequency of the heat and cold waves described in Section 3.2. The baseline specification is as follows:

$$\text{Height}_{ita} = \alpha + \sum_{j=-1}^4 \beta_j \text{Heat}_{itaj} + \sum_{j=-1}^4 \gamma_j \text{Cold}_{itaj} + \mathbf{x}'_{ita} \boldsymbol{\zeta} + \theta_a + \nu_{it} + \epsilon_{ita} \quad (1)$$

where  $i$  indexes the prefectures,  $t$  indexes the measured years, and  $a$  indexes the ages. The variable  $\text{Height}_{ita}$  is the height of either a boy or girl; Heat and Cold indicate heat and cold waves experienced  $j$ -years after the birth year, respectively; and  $\mathbf{x}_{ita}$  is a vector of the other control variables described in Section 3.3. In order to assess the importance of the prenatal and postnatal exposures, we use the weather shock variables in the year before birth, which is matched to measure the effects of in utero exposure by using weighted transformation (Section 3.2), to the four years after birth.  $\theta_a$  is an age-fixed effect,  $\nu_{it}$  is a prefecture-year-specific fixed effect, and  $\epsilon_{ita}$  is a random error term.

We employed the bilateral-specific, i.e., prefecture by year, fixed effects model (Balazsi, Matyas, and Wansbeek, 2018). These fixed effects can address time-varying unobserved factors, e.g., living standards, variations in pubertal growth spurts of children, and any macroeconomic price shocks. Because  $\hat{\beta}_j$  and  $\hat{\gamma}_j$  indicate the changes in height owing to a one unit increase in the measures of heat and cold waves, respectively, these estimated coefficients are likely to be negative.

The data used are less likely to be influenced by internal migration effects. In fact, an official report of the 1930 Population Census states that the proportion of children aged 0–11 years who had lived in their birth prefectures was approximately 95% (Statistics Bureau of the Cabinet, 1930, p. 130). A potential concern is, the potential spatial correlations in the height data (see Appendix B.1). Considering this, we

**Table 2**  
Effects of heat and cold waves on primary school children.

	Primary school boys			Primary school girls		
	(1)	(2)	(3)	(4)	(5)	(6)
Heat wave exposed in utero	0.027 [0.564]	-0.003 [0.929]	-0.005 [0.873]	0.030 [0.565]	-0.006 [0.795]	-0.010 [0.759]
at age 0	-0.050 [0.305]	0.002 [0.971]	-0.001 [0.945]	-0.056* [0.081]	0.006 [0.759]	0.012 [0.377]
at age 1	-0.077* [0.096]	0.009 [0.371]	0.012 [0.361]	-0.088 [0.121]	0.011 [0.119]	0.006 [0.515]
at age 2	0.030 [0.224]	-0.003 [0.777]	-0.004 [0.659]	0.025 [0.243]	-0.019 [0.461]	-0.013 [0.479]
at age 3	-0.058** [0.047]	0.013*** [0.001]	0.005 [0.591]	-0.057 [0.147]	0.014** [0.029]	0.008 [0.315]
at age 4	0.063 [0.231]	-0.013 [0.603]	-0.007 [0.613]	0.082 [0.239]	-0.040 [0.173]	-0.032 [0.113]
Cold wave exposed in utero	0.015** [0.036]	-0.014*** [0.003]	-0.016*** [0.003]	0.040* [0.081]	0.009 [0.665]	0.002 [0.897]
at age 0	0.010 [0.510]	0.005 [0.729]	0.001 [0.939]	-0.012 [0.117]	-0.009 [0.503]	-0.013 [0.381]
at age 1	0.006* [0.096]	-0.001 [0.967]	-0.002 [0.701]	0.013 [0.181]	0.002 [0.539]	-0.003 [0.509]
at age 2	-0.009 [0.480]	-0.005 [0.523]	-0.003 [0.677]	-0.011 [0.649]	-0.006*** [0.005]	-0.009** [0.011]
at age 3	-0.020** [0.034]	0.003 [0.125]	0.001 [0.745]	-0.030** [0.021]	-0.006 [0.403]	-0.006 [0.235]
at age 4	-0.000 [1.000]	-0.001 [0.941]	-0.003 [0.581]	0.002 [0.915]	0.001 [0.897]	-0.005 [0.595]
Control variables	No	No	Yes	No	No	Yes
Prefecture-year specific FEs	No	Yes	Yes	No	Yes	Yes
Age FEs	Yes	Yes	Yes	Yes	Yes	Yes
Lower bounds of the effects			-0.0145			-0.0083

Notes: The number of observations is 1692 for all the specifications. \*\*\*, \*\*, and \* represent the statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors are clustered at nine-area level. p-values from the wild cluster bootstrap resampling method robust to a small number of clusters in brackets. Lower bounds on cold wave coefficients estimated using the technique of Oster (2016) are reported at the bottom of the table. A conservative setting was employed. The maximum R-squared from a hypothetical regression of height on both observed and unobserved variables was assumed to be one. A value for the relative degree of selection on observed and unobserved variables was also assumed to be one, implying that the selection on unobservables is assumed to be equal to the selection on observables.

systematically divided the 47 prefectures into nine areas by following conventional geographical classifications of Japan (Appendix B.4). We then clustered our standard error at the area level to address both the heteroskedasticity across clusters and the correlation and heteroskedasticity within clusters (Bertrand, Duflo, and Mullainathan, 2004). In order to address the issue of the small number of clusters, we further adopt the wild cluster bootstrap-t method proposed by Cameron, Gelbach, and Miller (2008). The number of replications is fixed as 1000 for all the specifications. We confirmed that the results are unchanged if we replicate a large number of times. We execute regressions separately for the boys and girls subsamples to permit the effects of the weather shocks to vary across gender. All the regressions are weighted by the number of individuals in each prefecture-year cell.

#### 4.2. Baseline results

Table 2 presents the results for the baseline specification in Eq. (1). Columns 1–3 and 4–6 present the results for the boys and girls, respectively.

Column 1 presents the results for the specification with age-fixed effects, excluding both additional control variables and bilateral-specific fixed effects. The estimated coefficients are not as expected. However, when the bilateral-specific fixed effects were considered in

Column 2, we observed a statistically significantly negative coefficient on the cold wave variable as we expected. This implies that the fixed effects effectively capture the time-varying unobserved factors (Section 4.1). The estimated coefficients indicate that fetal cold wave exposure exerts a statistically significantly negative effect on the height of boys. This relationship remains unchanged if we add the additional controls in Column 3. This implies that mortality selection, early-life wealth levels, and observed socioeconomic and disease environments around birth are not correlated with weather shocks (see also Appendix A.2). Our baseline estimate in Column 3 reveals that an in utero increase in the exposure to 2-d spells of cold days, i.e., a cold wave by our definition (Section 3.2), reduces boys heights by 0.032 cm (0.016 × 2), which corresponds to a 0.02% decrease in height (Appendix C.2). We report the lower bound of the coefficients of the cold waves (in utero) at the bottom of Table 2 by employing the bounding procedure developed by Oster (2016). The bound reported in Column 3 is close to the estimated coefficient of the cold waves. This result implies that unobserved variables are less likely to affect our estimates, supporting the robustness of our finding.

Columns 4–6 correspond to the specifications in Columns 1–3. The estimated coefficients reported in Columns 4 and 5 are not as expected. When we added the additional controls and the fixed effects in Column 6, however, we observed a statistically significant negative coefficient

of the cold waves, as expected. This estimate indicates that an increase in the exposure to 2-d spells of cold days at the age of two reduces height by 0.018 cm ( $0.009 \times 2$ ), which corresponds to a decrease in height of approximately 0.02% (Appendix C.2). The lower bound reported at the bottom of Column 6 is close to the estimated coefficient of the cold waves and that the potential biases due to the omitted variables are limited. Although a statistically significant effect is only observed for the cold waves at the age of two, the estimated coefficients of the cold waves after birth (ages 0 to 4) are also negative. As discussed in Section 4.4, we find that the overall postnatal exposures to cold waves between the ages 0 and 4 have negative and statistically significant effects on girls heights in the alternative specifications based on an alternative exposure variable that captures the weather shocks between the ages 0 and 4. This implies that postnatal exposure to cold waves is more likely to affect height in girls than prenatal exposures.

Next, we calculate the magnitude of the weather shocks using our estimates reported in Columns 3 and 6 of Table 2. The median and maximum values of the cold waves exposure in utero are approximately 6 and 52, respectively. This indicates that the boys who were exposed to cold wave while in womb for 6 and 52 d tend to reduce their height by 0.096 and 0.83 cm ( $-0.016 \times 6$ ;  $-0.016 \times 52$ ), respectively. Similarly, the median and maximum values of cold waves (exposure at age two) are approximately 6 and 64, respectively. The corresponding stunting effects for the girls are 0.054 and 0.58 cm ( $-0.009 \times 6$ ;  $-0.009 \times 64$ ). We will provide a more detailed discussion on the magnitudes in Section 5.

A noteworthy observation here is that cold waves are more likely to impact child height. This result is consistent with the observations in previous studies in related fields, as described in the introduction section. Cold weather is itself likely to increase the calorie consumption of the human body. However, a more important issue is that cold weather shocks necessitate a trade-off between the expenditure on home fuel or clothes and that for food, because of budgetary constraints. These cold-weather budgetary shocks result in lower nutritional intake among children, particularly among poor households, as discussed in Section 2.2. Our discussion in Section 2.2 suggests that prenatal maternal stress might have also had a stunting effect on boys.

#### 4.3. Heterogeneous effects

Notwithstanding the consistency, the other potential factor may be associated with the difference in the occurrence probabilities of both waves. For example, the number of observations that had experienced at least one hot day at age two were 1224 out of the 1692 total observations, whereas those for the cold wave were 690. This implies that the cold waves defined herein are less likely to occur than the heat waves and thus, is likely to be more severe shocks for the human body. However, it is challenging to use a more conservative definition of heat waves owing to the data availability. In order to address this potential issue in the heat wave variable, we limit our sample to a colder region in order to remove the potential unobserved effects of heat weather shocks. Specifically, we excluded the sample points that had not experienced cold wave during our sampled period. Our subsample then contains 25 prefectures in the colder regions with an average temperature of 12.3 °C; this is on average 1.5 °C lower than that of our entire sample. Accordingly, a large part of these prefectures are located in the northeastern cold weather region (Fig. 2b).

Table 3 presents the results for the subsample. Columns 1–3 and 4–6 present the results for boys and girls, respectively. Age and bilateral-specific fixed effects and baseline control variables used in Table 2 are included in all the specifications. Note that the variables of heat waves are no longer included because we focus on the colder regions where the heat waves rarely occurred.

Column 1 reveals that an in utero increase in the exposure to 2-d spells of cold days reduces height in boys by 0.022 cm. Similarly, Column 4 indicates that an increase in the exposure to 2-d spells of cold

days at age two reduces height in girls by 0.022 cm. These estimates are not far from those reported in Columns 3 and 6 in Table 2. In Columns 2–3 and 5–6, we attempt to assess the heterogeneous treatment effects of weather shocks (Dell, Jones, and Olken, 2014). We tested the heterogeneities in the treatment effects with respect to the ages in Columns 2 and 5. We herein interacted the cold wave variable with the age group dummies, i.e., indicator variables for children aged either 8–9 or 10–11, to permit the impacts of exposure to vary across the ages of the exposed children. This specification is considered because if catch-up growth started in the primary school ages, the stunting effects of weather shocks are likely to diminish as they grow older (Frankenberg, Friedman, Ingwersen, and Thomas, 2017). In this case, the estimated coefficients on the interaction terms should become statistically-significantly positive, whereas the main effect is statistically-significantly negative. However, the results in Columns 2 and 5 provide evidence that there were no significant catch-up growths either in boys or girls. Although one must be weary of the later catch-up growth in boys, which is not captured here in this study, the results of this study imply that fetal exposure to cold waves have persistent stunting effects on primary school children globally.

We also tested the heterogeneous treatment effects across the different types of region in terms of the temperature in Columns 3 and 6. Individuals living in warmer regions are vulnerable to cold waves as they tend to use cooler homes and to wear fewer clothes (The Eurowinter Group, 1997). This indicates that the impacts of exposure to cold waves are likely to be stronger in warmer regions. We then formed a term, which is the product between the cold wave variable and an indicator variable that takes the value one for the regions with an average temperature over the median value (12.76 °C). The estimated coefficients on this interaction term are statistically significantly negative both in Columns 3 and 6. This implies that the stunting effects of cold waves are likely to have been stronger in warmer regions than in cooler regions. Column 3 indicates that an in utero increase in the exposure to 2-d spells of cold days reduces the height in boys by 0.02 cm in cooler regions and by 0.106 cm ( $0.02 + 0.086$ ) in warmer regions. The estimates in Column 6 indicate that an increase in the exposure to 2-d spells of cold days at age two reduces the height in girls by 0.022 cm in cooler regions and by 0.2 cm ( $0.022 + 0.178$ ) in warmer regions. This implies that the marginal stunting effects on boys and girls were approximately five and nine times larger, respectively, in the warmer regions of the northeastern cold weather region. However, the maximum number of days of exposure to cold weather in utero and at age two in this warmer region are 2.14 and 2.59, respectively, because of its warmer climate. Notwithstanding this, the maximum magnitude of cold waves on the boys and girls in the warmer region would be approximately 0.1 cm ( $0.053 \times 2.14$ ) and 0.2 cm, respectively. This value is smaller than that in the coldest region calculated using our baseline results as described in Section 4.2, i.e., 0.83 cm and 0.58 cm.

The foregoing analysis indicates that the results obtained using our baseline specifications, reported in Table 2, is robust against the potential unobserved effects of heat waves. We also found evidence that there were no significant catch-up growths in primary school children. In addition, we observed that the stunting effects of cold waves are higher in warmer regions than in cooler regions. However, the estimated magnitude in warmer regions is still smaller than that in the coldest northeastern regions, implying that the stunting effects in the coldest regions are more likely to be problematic in terms of their magnitude. Although testing potential heterogeneous effects with respect to height is another important research topic, our SSPE data may not be able to sufficiently meet the conditions for consistency and asymptotic normality of the fixed effect quantile regression estimator (c.f. Kato, Galvao, and Montes-Rojas, 2012). Therefore, we set this topic as one for future research.

**Table 3**  
Effects of cold wave on primary school children: subsample in northeastern cold weather region.

	Primary school boys			Primary school girls		
	(1)	(2)	(3)	(4)	(5)	(6)
Cold wave (in <i>utero</i> for boys; at age 2 for girls)	-0.011** [0.010]	-0.011** [0.010]	-0.010** [0.010]	-0.011*** [0.007]	-0.012*** [0.007]	-0.011*** [0.007]
Cold wave × Age 8–9		0.000 [0.896]			-0.002 [0.815]	
Cold wave × Age 10–11		0.001 [0.886]			0.007 [0.611]	
Cold wave × Warmer region			-0.043* [0.090]			-0.089*** [0.007]
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Prefecture-year specific FEs	Yes	Yes	Yes	Yes	Yes	Yes
Age FEs	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The number of observations is 846 for all the specifications. In Columns 1–3, cold wave indicates the cold waves exposed to in utero. In Columns 4–6, cold wave indicates the cold waves exposed to at age 2. \*\*\*, \*\*, and \* represent the statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors are clustered at the seven-area level. p-values from the wild cluster bootstrap resampling method robust to a small number of clusters in brackets.

#### 4.4. Sensitivity checks

Before we begin the discussion, we assess the robustness of our baseline results in Table 2 by using alternative specifications. Table 4 presents the results. Columns 1–4 and 5–8 present the results for the boys and girls, respectively.

We employed the bilateral-fixed effects model to control for unobserved time-varying factors for each prefecture–year cell. This implies that substantial confounding factors in the measure years have been effectively controlled for in our baseline specification in Table 2. That is, our results are likely to be sensitive to the cohort effects that have not been controlled for in the baseline specification. Therefore, we added a few control variables to address this potential issue. In Columns 1 and 5, we intend to consider the socioeconomic environment surrounding birth by controlling for the school enrolment rate in birth year (Brown, 2011). The fetal death rate in birth year is also included to further control for potential mortality selection and wealth levels (Bozzoli, Deaton, and Quintana-Domeque, 2009). The results are close to our baseline results reported in Columns 3 and 6 of Table 2. This verifies that our main observation should be robust against the inclusion of the potential cohort effects. We conducted the same exercise for the specifications in Table 3 and confirmed that the results are largely unchanged (see Appendix C.3 for the results).

We next test the sensitivity to variable definitions. In Columns 2 and 6, we define a heat wave as the annual average number of days on which the minimum temperature exceeds 25 °C for at least three days. Similarly, a cold wave is defined as the annual average number of days on which the maximum temperature is below 0 °C for at least three days. We defined weather shocks by using more specific definitions than in Columns 1 and 5 of Table 4. Correspondingly, we found larger estimates in Columns 2 and 6. This supports the evidence that our definition of the weather shocks can effectively capture the intensity of the heat and cold waves. It is interesting to note that we also found a weak but statistically significant effect of cold wave exposure at age one, supporting the evidence that postnatal exposure is more likely to affect girls. We further conduct the placebo test by including heat and cold waves in the 2 y before birth in Columns 3 and 7. Because weather shocks before conception cannot directly affect infants, the estimated coefficients on these pre-conception variables should be close to zero. The estimated coefficients on these variables are observed to be statistically insignificant. This result also supports the validity of our baseline specifications.

In Columns 4 and 8, we test the validity of our definition of the weather shock variables by using broader definitions. In both the columns, we define heat wave as the annual average number of days on

which the maximum temperature exceeds 30 °C on at least two days. Similarly, cold wave is defined as the annual average number of days on which the minimum temperature below 0 °C is at least two days. Our use of more conservative definitions in our main analysis implies that the impacts of weather shocks under lenient criteria should be negligible. In fact, the mean values of these heat and cold waves (exposure in utero) are approximately 36.7 and 51.3 d, respectively. These values are considerably larger than those used in Table 2 as the corresponding values under the conservative definitions are approximately 3 and 2 d, respectively. Appendix C.4 describes the geospatial variations of these alternative weather shock variables. As we expected, the estimated coefficients are statistically insignificant in most cases (Columns 4 and 8). This result indicates that our variable of interest under the conservative definitions can reasonably capture the intensity of the cold waves.

Finally, we estimate the overall effects of postnatal exposure to weather shocks. Table 5 presents the results obtained using the specifications based on an alternative exposure variable that captures the weather shocks between the ages 0 and 4 rather than the shocks at each age. Columns 1 and 2 confirm that the prenatal (postnatal) exposure to cold waves matter for boys (girls). This result remains unchanged if we include the additional control variables in Columns 2 and 4. Column 4 confirms that the overall effects of postnatal exposure to cold waves on girls heights are statistically significantly negative. The estimate indicates that an increase in the exposure to 2-d spells of cold days between the ages 0 and 4 reduces girls heights by 0.016 cm. In Appendix C.3, we have also confirmed that our results for flexible specifications, reported in Table 3, are robust if we use an alternative exposure variable that captures the weather shocks between the ages 0 and 4.

## 5. Discussion

We determine the adverse effects of exposure to cold weather in early-life on the height of children in an industrializing Japan. Because our findings are for an industrializing country, one must be careful about applying induced implications to today's developed countries. Overall, our results are consistent with previous studies focusing on the developing countries mentioned in the Introduction section (Skoufias and Vinha, 2012; Groppo and Kraehnert, 2016).

For the median length of cold wave exposure, approximately 6 d, our estimates indicate that the boys who experienced the shocks in utero had their heights reduced by 0.1 cm, whereas the girls who experienced the shocks at age two were shorter by 0.05 cm. However, for the coldest region in the northeastern part of the Japanese archipelago, where cold waves are experienced 50–65 days on average, the stunting



**Table 4**  
Results for alternative specifications: specification tests, falsification tests, and alternative variable definitions.

	Primary school boys				Primary school girls			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Heat wave exposed at age -2			0.009 [0.509]	-0.003 [0.405]			0.004 [0.743]	-0.003 [0.595]
in utero	-0.005 [0.889]	-0.012 [0.739]	-0.017 [0.491]	-0.002 [0.901]	-0.012 [0.777]	-0.015 [0.817]	-0.017 [0.749]	-0.008 [0.379]
at age 0	-0.001 [0.945]	0.020 [0.499]	0.024 [0.393]	0.000 [0.467]	0.013 [0.347]	0.046 [0.227]	0.048 [0.173]	0.000 [0.609]
at age 1	0.012 [0.343]	0.009 [0.727]	0.010 [0.755]	-0.002 [0.941]	0.005 [0.601]	0.008 [0.583]	0.009 [0.637]	-0.002 [0.847]
at age 2	-0.004 [0.611]	0.011 [0.709]	0.013 [0.721]	0.001 [0.783]	-0.014 [0.437]	-0.002 [0.961]	-0.001 [1.000]	0.006 [0.413]
at age 3	0.005 [0.565]	0.005 [0.779]	0.007 [0.701]	0.001 [0.913]	0.008 [0.329]	0.014 [0.121]	0.015 [0.147]	-0.001 [0.937]
at age 4	-0.008 [0.613]	0.004 [0.743]	0.005 [0.665]	0.002 [0.551]	-0.033 [0.113]	-0.030 [0.333]	-0.030 [0.315]	-0.000 [0.967]
Cold wave exposed at age -2			0.001 [0.897]	-0.001 [0.223]			-0.004 [0.497]	0.001 [0.769]
in utero	-0.016*** [0.003]	-0.018*** [0.003]	-0.017*** [0.003]	-0.001 [1.000]	0.001 [0.959]	0.003 [0.935]	0.002 [0.949]	-0.001 [0.833]
at age 0	0.000 [0.971]	-0.002 [0.959]	-0.001 [0.999]	-0.000 [1.000]	-0.014 [0.349]	-0.014* [0.081]	-0.015* [0.081]	-0.001 [0.679]
at age 1	-0.003 [0.655]	-0.004 [0.337]	-0.004 [0.483]	0.002 [0.453]	-0.003 [0.547]	-0.005 [0.469]	-0.006 [0.475]	0.004 [0.331]
at age 2	-0.002 [0.709]	-0.002 [0.631]	-0.001 [0.747]	0.002 [0.615]	-0.009*** [0.005]	-0.015*** [0.005]	-0.017*** [0.005]	0.001 [1.000]
at age 3	0.000 [0.851]	0.003 [0.441]	0.003 [0.145]	0.001 [0.379]	-0.007 [0.195]	-0.007 [0.275]	-0.010 [0.195]	0.002 [0.319]
at age 4	-0.004 [0.449]	-0.004 [0.453]	-0.004 [0.517]	-0.002 [0.439]	-0.005 [0.563]	-0.002 [0.937]	-0.004 [0.905]	-0.000 [0.903]
Alternative key variables	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Baseline control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
School enrolment rate in birth year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fetal death rate in birth year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prefecture-year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Age FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The number of observations is 1692 for all the specifications. \*\*\*, \*\*, and \* represent the statistical significance at the 1%, 5%, and 10% levels, respectively. The standard errors are clustered at the nine-area level. p-values from the wild cluster bootstrap resampling method robust to a small number of clusters in brackets.

effects on the boys and girls were approximately 0.8 and 0.6 cm, respectively. We also tested the heterogeneous effects of treatment across different age groups and different types of regions in terms of warmth. While we found no evidence of catch up growth in cases where there was exposure to cold waves, we found that the stunting effects of cold waves depend on the overall temperature of the locations. Specifically, the marginal effects are stronger in the warmer regions than in the cooler regions. This supports the evidence that individuals in the warmer regions, who are accustomed to a warmer climate, are more vulnerable to abrupt cold weather shocks (The Eurowinter Group, 1997). However, the probability of experiencing cold waves in warmer regions is, on average, more than 40 times less than that in colder regions. The average number of days with cold waves (in utero) in the warmer and cooler regions are 0.2 and 8.9, respectively. Accordingly, the maximum magnitude of cold waves on the boys and girls in the warmer region would be approximately 0.1 cm and 0.2 cm, respectively. These estimated magnitudes of such cold waves in the warmer regions are smaller than those in the coldest regions described above. This finding implies that cold waves have obvious stunting effects, especially in the coldest region in the northeastern part.

Although the average figures of the effects of cold waves are

considered to be small, the magnitudes in the coldest region, i.e., more than half a centimeter to roughly one cm, are likely to have exerted substantial impacts on the child population at that time. In fact, Mazumder, Almond, Park, Crimmins, and Finch (2010) found that a 0.1-cm decline in final height is associated with a 5%-higher probability of enduring cardiovascular diseases, and an increase if more than 10% in the incidences of heart diseases, especially ischemic heart disease, in later life. Lawlor, Ebrahim, and Davey Smith (2002), Lawlor, Taylor, Smith, Gunnell, and Ebrahim (2004) found similar associations between shorter stature and higher risk of Type II diabetes, heart disease, and osteoarthritis. As discussed in the introduction section, stunted growth exerts negative causal effects on financial income and can also be associated with social inequalities later in life (Lindqvist, 2012; de Onis and Branca, 2016). For instance, stunting by half a centimeter is associated with 2–3% decrease in financial income later in life (McGovern et al., 2017). Considering these, one must be wary of the long-run adverse effects of a more than half a centimeter stunting due to early-life exposure to weather shocks. The lingering stunting effects on children are likely to have caused a certain loss of human capital accumulation during the industrialization of Japan, similar to cases of epidemics of infectious diseases such as influenza (Lin and Liu, 2014).

**Table 5**

Results obtained using the alternative specifications: alternative definition of the postnatal exposure variable.

	Primary school boys		Primary school girls	
	(1)	(2)	(3)	(4)
Heat wave exposure in utero	−0.003 [1.000]	−0.003 [1.000]	0.011 [0.701]	0.011 [0.739]
at ages 0–4	0.002 [0.847]	0.002 [0.855]	−0.001 [0.989]	−0.001 [0.931]
Cold wave exposure in utero	−0.013*** [0.003]	−0.014*** [0.003]	0.002 [0.885]	0.001 [0.963]
at ages 0–4	−0.002 [0.349]	−0.002 [0.335]	−0.008*** [0.005]	−0.008*** [0.005]
Baseline control variables	Yes	Yes	Yes	Yes
School enrolment rate in birth year	No	Yes	No	Yes
Fetal death rate in birth year	No	Yes	No	Yes
Prefecture-year specific FEs	Yes	Yes	Yes	Yes
Age FEs	Yes	Yes	Yes	Yes

Notes: The number of observations is 1692 for all the specifications. \*\*\*, \*\*, and \* represent the statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors are clustered at the nine-area level. p-values from the wild cluster bootstrap resampling method are robust for a small number of clusters in brackets.

We observe that the stunting effects of prenatal cold wave exposure was observed only in boys. As discussed in Section 2.2, our result implies that while the stunting effects of fetal shocks in girls are negligible in the statistical sense, those in boys are more prominent because the male fetuses are more likely to be impacted by ambient stresses in utero. A higher vulnerability in males who experienced fetal exposure to ambient stresses is indeed consistent with a set of previous studies. For instance, Garthwaite (2008) and Mazumder et al. (2010) found that, in the United States, males who were exposed to fetal influenza are more likely to experience adverse health in later life than women. Neelsen and Stratmann (2012); Lee (2014); Lin and Liu (2014), and Ogasawara (2018c) also observed similar effects of fetal shocks on males in Switzerland, Korea, Taiwan, and Japan, respectively. These weights of evidence support our findings on the stunting effects of prenatal exposures.

We also observe the stunting effects of postnatal exposures to cold waves only in girls. A potential explanation is the parental compensatory investments for boys based on the patriarchal institution of prewar Japan (Ramseyer, 1996). This strong gender preference in favor of males could lead to a gender bias against females in intra-household allocations, especially in terms of educational investments (Ogasawara, 2017, 2018a). This implies that female infants might had been less protected than the male infants against cold waves. In fact, we observe more obvious effects of postnatal exposure in girls in warmer regions; however, the heterogeneity in the effects is substantially smaller in the case of prenatal exposures in boys. A likely explanation would be that parents are unable to identify the sex of their children during pregnancy and would thus take the same precautions against cold regardless of the sex of the fetus. In contrast, parents take on more biased precautionary behaviors after the birth of their children. However, one must be cautious not to conclude this as we do not use the individual data with the information on date of birth. Although we will be able to further test this hypothesis using data on twins of different genders; unfortunately, it is difficult to further delve into the mechanisms of gender biases in the stunting effects on children. Further studies are required to investigate the critical period for stunting in children and the role that

gender plays.

In the process of economic development, households are more likely to be compelled to the trade-off between the expenditure for heating and that for food. In addition, heaters are less likely to have been introduced in the houses, particularly of poor households. Our result argues that under such severe conditions, cold waves postulate heavy long-run burden on child growth. These adverse effects are stronger in the warmer regions where households are not capable of addressing abrupt climatic changes, owing to a shortage of anti-cold facilities and equipment. A highly detailed study on the heterogeneities of the long-run effects of cold weather shocks in relatively warmer regions can be another avenue for research. A potential policy recommendation can include preparation for unforeseen cold waves, such as cold-weather clothing and firewood, particularly in the warmer regions in certain developing countries.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ssmph.2018.11.001.

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