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Life Course Consequences of Low Birth Weight: Evidence from Japan

松島 みどり、清水谷 諭、山田 浩之

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Institute for Economic Studies, Keio University
2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan
ies-office@adst.keio.ac.jp

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JEL Classification: I14, J14, I21, I31

キーワード: birth weight; long-term outcome; JSTAR; Japan

【要旨】

This study provides the first evidence on a variety of life course outcomes of birth weight in Japan by employing new datasets covering the middle and older generations. We have several interesting observations. First, low birth weight is significantly associated with adverse outcomes in early life including school performance and self-rated health. Second, no negative effect of low birth weight is found on educational attainment or primary job status. Third, health outcomes due to low birth weight at older ages are not negatively affected except for difficulty in mobility and higher risk of diagnosis with hypertension or diabetes. Overall, our findings suggest that the negative effect of lower birth weight seems to fade out over the life course.

松島 みどり
大阪商業大学公共学科
〒577-0036
大阪府東大阪市御厨栄町４－１－１０
midori@daishodai.ac.jp

清水谷 諭
公益財団法人　中曽根康弘世界平和研究所
〒105-0001
東京都港区虎ノ門3-2-2 虎ノ門30森ビル 6F
sshimizutani@iips.org

山田 浩之
慶應義塾大学経済学部
〒108-8345
東京都港区三田2-15-45
hyamada@econ.keio.ac.jp

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Life Course Consequences of Low Birth Weight: Evidence from Japan*

by

Midori Matsushima, Satoshi Shimizutani, and Hiroyuki Yamada**

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Abstract

This study provides the first evidence on a variety of life course outcomes of birth weight in Japan by employing new datasets covering the middle and older generations. We have several interesting observations. First, low birth weight is significantly associated with adverse outcomes in early life including school performance and self-rated health. Second, no negative effect of low birth weight is found on educational attainment or primary job status. Third, health outcomes due to low birth weight at older ages are not negatively affected except for difficulty in mobility and higher risk of diagnosis with hypertension or diabetes. Overall, our findings suggest that the negative effect of lower birth weight seems to fade out over the life course.

Key words: birth weight; long-term outcome; JSTAR; Japan
JEL: I14, J14, I21, I31

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** Midori Matsushima; Assistant Professor, Osaka University of Commerce, Postal Address: 4-1-10 Mikuriyasakae-machi, Higashiosaka-shi, Osaka 577-8505 Japan, Tel: +81-(0)6-6785-6246 E-mail: midori@daishodai.ac.jp.
Satoshi Shimizutani; Visiting Research Fellow, Nakasone Yasuhiro Peace Institute, Postal Address: Toranomon 30 Mori Building 6F, 3-2-2 Toranomon, Minato-ku, Tokyo 105-0001 Japan Tel: +81-(0)3-5404-6651; E-mail: sshimizutani@iips.org; sshimizutani@gmail.com.
Hiroyuki Yamada (Corresponding author); Professor, Faculty of Economics, Keio University, Postal address: 2-15-45 Mita, Minato-ku, Tokyo 108-8345 Japan, Tel: +81-(0)3-5427-1271 E-mail: hyamada@econ.keio.ac.jp.

1. Introduction

This is the first study in Japan to investigate consequences of low birth weight (henceforth, LBW), an indicator of intrauterine malnutrition, over the life course. The interest among health researchers on the LBW effect on health and intellectual outcomes over the life cycle dates back to over half a century ago (Asher 1946). Back then, there were two competing views on the ultimate prognosis of a premature baby: one that was optimistic and another that was pessimistic based on a small number of clinical samples in the U.S. and Europe. Recently, researchers have started to apply rigorous econometric models to large size datasets to discern the LBW effect from genetics and environment surrounding the babies. Now, a growing body of evidence shows a negative impact of LBW on childhood and adulthood health, educational achievement, and labor outcomes. This evidence is confirmed in many countries including both developed and developing economies (Currie (2011) for developed countries; Currie and Vogl (2013) for developing countries).[1]

In contrast to this intensive research, the Japanese case has been left unexplored largely due to data limitation. To our knowledge, there are only two studies on the LBW effect in economics literature in Japan. Kawaguchi and Noguchi (2012) uses nationwide panel data of children born in 2011 and finds a statistical difference between LBW babies and non-LBW babies in child development at age $2_{1/2}$ years but does not find a

[1] Some of these papers are as follows. Behrman and Rosenzweig (2004) explores the LBW effect on schooling and wages, and Royer (2009) examines the effect on educational achievement, and next-generation birth weight, both of which used U.S. data. Oreopoulos et al. (2008) uses Canadian data to reveal health outcomes during adolescence, educational attainment, and welfare assistance take-ups. Black, Devereux and Salvanes (2007) looks at LBW outcomes including height, IQ, educational attainment, employment, earnings, and next generation outcomes in Norway. For outside western countries, Lin and Liu (2009) and Xie, Chou and Liu (2016) used Taiwanese data focusing on the LBW effect on education and BMI. Rozenzweig and Zhang (2013) examined the LBW effect on educational achievement in China and Baharadwaji, Ederhard, and Neilson (2018) explores it in Chile.

difference at age $6_{1/2}$ years.[2] Nakamuro, Uzuki and Inui (2013) examines the LBW effect on academic performance and earnings by using twin data obtained through a non-random web-based survey. They reveal that birth weight has a causal effect on academic achievement around the age of 15, but it does not have the same effect on higher years of schooling and earnings. However, both studies are silent about the LBW effect over the long-term life course.

This study provides first evidence on the short-term (childhood), mid-term (adulthood) and long-term (old age) effect of LBW on a variety of outcomes in Japan using a new dataset on the middle and older generations. By doing so, we aim to contribute to the growing literature by filling a gap in knowledge on LBW effect between Japan and other countries. The significance of examining LBW effect at each life stage in Japan is justified by several aspects.

First, Japan enjoys the longest life expectancy in the world and is best suited to investigate the LBW effect at old age. To our knowledge, Bharadwaj, Lundborg, and Rooth (2018) is the only paper that examines LBW effects over the life course (the highest age is 84 and the average age is 68). They examine the impact of LBW on educational attainment, income, mortality and some chronic illnesses in Sweden. Despite the adverse labor outcomes during at middle-age found by Black, Devereux and Salvanes (2007) and Oreopoulos et al. (2008), their study shows that the adverse LBW effect on income fades out for males after the 50s and no effect on mortality is found for females. Our study complements the past literature by looking at important outcome variables at old age such as self-evaluated health and life satisfaction measurements and

[2] The measurements of child development are commonly used by paediatricians such as ‘Does your child say words such as mom?’ at an age of $2_{1/2}$ and the number of children that child play with at an age of $6_{1/2}$ years.

cognitive ability, which are not yet well studied in the literature.

Second, birth weight has continued to decline in Japan and the proportion of LBW babies has increased over the past 35 years. In 2016, Japan's average birth weight was 3.0 kg and 9.4% of new born babies were classified as LBW (less than 2,500g) which is higher than the average of OECD countries by 3 percentage points (OECD, 2015).

Medical literature reveals that the high rate of LBW babies is attributed to strict weight control for pregnant women between the 1960s and 1980s to reduce the risk of maternal and infant death (Oda 2012). While the risk of maternal death has been reduced significantly under technological development, there is still a widespread belief that giving birth to a small baby and raising the child to grow big is a good practice (Shimizu 2016; Yokoyama 2015).[3] Hence, an investigation of Japan's case is rather important for future generations and public policy.

Third, this study may contribute to providing new findings that could uncover possible mechanisms of the LBW effect in Japan's specific context. Japan started to provide primary healthcare including health check-ups at school that reached all school children after World War II and introduced universal health insurance coverage guaranteeing everyone access to healthcare in 1961. Thus, LBW babies may have benefitted from the Japanese health policy and system, which may not be the case in other countries. The advantage of this study is to provide additional suggestive information to disentangle its mechanism by examining changing effects of LBW over the life course.

[3] Indeed, it is quite recent that Japanese medical literature has started to report clinical evidence on the relationship between LBW and higher risk of diabetes, impaired glucose tolerance, hypertension and hyperlipidaemia (Endo et al. 2010; Matsuda 2016).

This paper proceeds as follows. Section 2 describes the dataset. Section 3 introduces empirical strategy and presents the results and Section 4 discusses them with additional analysis. Section 5 concludes.

2. Data

We use micro-level data from *Japanese Study of Age and Retirement* (JSTAR), a sister survey of the *Health and Retirement Study* (HRS), *English Longitudinal Survey on Ageing* (ELSA), S*urvey on Health, Ageing and Retirement in Europe* (SHARE) and others around the world. It is world-standard longitudinal data on the middle and older generations in Japan that collects very rich information on family formation, health, employment and economic status, and social participation. The baseline sample is individuals aged 50 to 75 who are randomly chosen based on household registration in a total of 10 selected municipalities with a response rate of approximately 60%.

This study uses the sample from Hiroshima and Sendai cities which include additional information during childhood and employment status at an age of 54 as well as a variety of measurements of quality of life in elderly ages. JSTAR began in 2007 targeting five municipalities in eastern Japan including Sendai. Hiroshima was first included in the third wave conducted in 2011. We use old age outcome variables provided between 2007 and 2015, with more recent responses when available for the purpose of examining older age effects. In addition to this data, we use information from a follow-up survey conducted in 2017 which is available only in Hiroshima and Sendai. This follow up survey was conducted in order to gain information on childhood health and school performance as well as employment status at the age of 54 (before retirement age). After data cleaning, we obtain 278 individuals who are aged from 52 to

81 and whose birth weight data, the critical variable in this study, is available. While the sample size is not large, one of the advantages of JSTAR over administrative data is that it contains rich information on a wide variety of outcomes including subjective evaluation of life and health, which is as important as an objective health measurement in old age when one's quality of life is considered.

Before proceeding to our empirical strategy, we confirm that the data on birth weight in JSTAR, the main variable in this study, does not deviate from the national average in Japan. The JSTAR survey conducted in 2015 provides us information on prematurity/LBW; a premature baby is one born before he/she is fully developed (born before full-term) while a LBW baby is one simply born at a weight under 2,500g. Although "premature" and "low birth weight" are not the same in medical terminology, they were previously used interchangeably in Japan (Sato 2012), so we use the term "LBW" throughout our paper to cover both types. In the questionnaire, respondents were asked to answer birth weight (in kilograms) if they have the record in a mother-child handbook (*boshi-techo*) or they have heard it from someone. If they did not know the weight, they were requested to answer whether they were a premature baby or not.

In order to retain as much data as possible, we create a binary variable to take 1 if the respondent was a LBW baby (including premature) and 0 otherwise. After excluding "no response" samples, the proportion of LBW babies is 10.4% in our sample. According to National Vital Statistics, the average proportion of LBW is 7.4% in 1951 and 7.1% in 1960 (Boshi Hoken Eisei Kenkyukai 2014).[4] The corresponding figure is 7% in our sample if we compute the average among individuals born between 1951 and

[4] There are no vital statistics between 1951 and 1960. Unfortunately, there is no data on distribution of birth weight available in the statistics.

1960. Moreover, the national average birth weight in 1951 and 1960 is 3.14 kg for males and 3.06 kg for females, which is again close to 3.1 kg among individuals born between 1951 and 1960 in our sample. While the sample size is not large in our dataset, the average weight at birth and the proportion of LBW are close to those in the national vital statistics.

Next, we describe our outcome variables. The detailed description of constructing variables is available in the Appendix. First, we investigate childhood health and school performance as short-term (childhood) outcomes. We use self-rated health during childhood, experience of chronic illness from birth to age 15, and school performance at age 10. We create a binary variable to take 1 if self-rated health status is very good or good and 0 otherwise ("*Health_child*") and an indicator variable to take 1 if the respondent reported experience with more than one chronic illness from birth up to age 15 ("*Chronic_child*"). These childhood health indicators represent general health status (self-rated health) and relatively severe illness (chronic illness). School performance was self-assessed by the respondent. We make binary variables to take 1 if self-rated performance in Japanese language or mathematics at age 10 is very good or good and 0 otherwise ("*Japanese*" and "*Math*," respectively).

Second, as medium-term (adulthood) outcomes, we look at highest educational attainment and employment status at age 54, which is considered to reflect a prime job. We create several binary variables with different cut-offs: "*Atleast_high*" to indicate respondents with at least some high school education; "*Grad_high*" to indicate respondents who are high school graduates; "*Atleast_uni*" to indicate respondents with at least some university education; "*Grad_uni*" to indicate respondents who are university graduates. Moreover, we create three indicator variables for employment status; “*Fulltime”* to show working as a full-time at age 54; “*Large_enterprise”* to show working at larger enterprise (at least 300 employees); *“Full_large_enterprise”* to show working at larger enterprise (at least 300 employees) as a full-time worker.

Third, we examine self-rated health, medical diagnosis, cognitive ability, mobility, mental well-being and life satisfaction as long-term (old age) outcomes. These variables are available in JSTAR from 2007 to 2015.[5] Self-rated health is the same as in the childhood health and we make an indicator to take 1 if self-rated health status is very good or good and 0 otherwise (“*Health*”). We also make a binary variable to take 1 if the respondent reported any difficulties in activities of daily living (ADL) and 0 otherwise (“*Mobility”*). Mental well-being is measured by using CES-D (Center for Epidemiologic Studies Depression Scale). We construct a binary variable to take 1 if the respondent reported having depressive symptoms (CES-D score >=16) and 0 otherwise (“*Depression*”). Turning to cognitive ability, three measurements are used in JSTAR: orientation, memory, and numeracy. We create three binary variables for each measurement to take 1 if a respondent is regarded as impaired and 0 otherwise; the cut-off is whether a respondent failed to state the date of the survey correctly (“*Orientation_imp*”), whether a respondent failed to recall more than 2 words (“*Memory_imp*”) and whether a respondent failed in the first two questions (“*Numeracy_imp*”).[6] Moreover, we create binary variables to take 1 if the respondent reported having ever been diagnosed with heart disease, hypertension, hyperlipidaemia, stroke, diabetes, ulcer, osteoporosis, cataract, urination, dementia, or cancer and 0 otherwise. Finally, we set up binary variables to indicate whether a respondent reported

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[5] When questions were asked in every survey year, and respondents answer to every survey, we use the one obtained in 2015 in order to analyse the outcomes at older age.

[6] The estimation results are unchanged if we change the treatment of the variables related with depression state or cognitive ability. See the next section.

he/she is satisfied or relatively satisfied with life as a whole (“*life_satisfaction*”), habitat (“*habitat_satisfaction*”), assets (“*asset_satisfaction*”), family (“*family_satisfaction*”), and leisure (“*leisure_satisfaction*”).

Table 1 reports the descriptive statistics for those outcome variables. First, we see that the average among individuals with LBW is worse in all the indicators during childhood. Second, at the adulthood stage, we observe that LBW seems to be disadvantageous in continuing education to undergraduates and in working for large firms. Third, most of the health indicators for old age outcomes are unfavorable for individuals with LBW. In the lower part of Table 1, however, we do not see large differences between individuals with LBW and non-LBW in the variables used in the regression analysis as covariates.

The exception is socio-economic status during childhood ages. The SES of their parents is a composite indicator of number of rooms per person in their house at age 10 (excepting bathroom, kitchen, and corridor), number of books in their house at age 10 (excepting magazines, newspapers, and textbooks), and household economic wealth from birth to age 15.[7] The SES index is created by using principal component analysis. The number of rooms per person is regarded as household long-run wealth (MacKenzie, 2005), the number of books strongly relates to parents’ education (Martins and Veiga, 2010), and household economic wealth (subjective) represent relative wealth. Because these are assumed to relate to both birth weight and outcome variables, we regard these variables as to control family factors. The bottom of Table 1 shows that no-LBW individuals hold a significantly higher score in the mean value or is there a larger

[7] In the questionnaire, economic wealth is asked given the choice of: well-off, around average, poor, and changed according to time. Although the number is negligent, there were people who chose the answer of “changed according to time” (less than 5%). For the purpose of maintaing the sample size, we included these samples into “around average.”

variation than that for LBW individuals. This comes from the large variation in the number of books in households during childhood.

3. Empirical analysis

We share the spirit of Bharadwaj, Lundborg, and Rooth (2018) which examines long-run outcomes of LBW using twins data in Sweden. However, our data does not contain twins or siblings and allows us to employ a twins/siblings fix effect model. Thus, we control possible factors that are relevant to birth weight and outcome variables, and consider following model for our analysis.

(1) $Y_{ij} = \beta BW_i + \gamma X_i + \delta Z_j + \varepsilon_{ij}$

where Y_{ij} is an outcome of individual *i*, belonging to family *j* and BW_i is LBW dummy taking 1 if an individual *i* is a LBW one. X_i are time invariant individual specific characteristics including birth year, sex, and education (for older age) and Z_j is a vector of variables related to family depending on outcome variables. The coefficient of interest is β, which is the birth weight effect. The type of outcomes is categorized at each life stage: short-term (childhood), medium-term (adulthood), and long-term (old age). We create a binary variable for each outcome variable and use a linear probability model for all regressions.

Table 2 reports the results on the short-term (childhood) outcomes. In the regression, we control for sex, birth year, birth before the end of WWII, residential municipality, and household SES during childhood. The coefficients show adverse outcomes to childhood health and school performance. The left-side columns report that it is likely for LBW individuals to have not had good health conditions as there is approximately 7% of respondents who report having had at least one chronic illness between birth and 15 years old. Although not significant, the negative sign also shows that LBW individuals report lower self-rated health status. Moreover, the right-hand side columns show that LBW individuals are more likely to report that they underperformed in Japanese language and mathematics at age 10. The self-rated assessment score is significantly lower for LBW individuals and the marginal effects suggest that it is about 13 to 19% less likely for LBW individuals to evaluate their school performance as good or very good. Overall, estimation results reveal that LBW has adverse effects on health and school performance in the childhood period.

Tables 3 and 4 report the results for the middle-term (adulthood) outcomes. In the regression, we control for sex, residential municipality, respondent's age, and birth before the end of WWII, and household SES to regress educational attainment. We add educational attainment as a control variable in the employment status regression. Table 3 shows the results of LBW impact on educational attainment. We see no significant difference between LBW and non-LBW individuals in any cut off level at 10% significance level. Since the sign of marginal effects are negative and the standard error is small for *Atleast_high* (having at least some high school education), it may be better to be careful of confirming that there is no negative effect on educational attainment at all. However, at least, we cannot find clear evidence of adverse outcome of LBW on educational attainment. Table 4 shows the results of LBW impact on employment status at age 54. Again, we do not observe any significant effect of LBW. Looking at the sign of *Large_enterprise*, and *Full_large_enterprise*, LBW individuals have lower rates of employment at large companies but the gap is not statistically significant. In sum, we find no statistical difference in highest educational attainment or employment status at age 54 and it seems that any adverse effect of LBW is not detected.

Tables 5, 6, and 7 show the results for the long-term (old age) outcomes. The control variables are the same as those in the regression of employment status. In addition, we include adulthood economic status and health behavior, which are normally considered to affect health status. Since there are many missing data on economic wealth in JSTAR, we use the information of whether a respondent owns a house with land. We use information on smoking habit in the present and the past as health behavior.

Table 5 reports the estimation results of LBW impact on overall health, mobility, depression, and cognitive ability. First, we see a negative coefficient for self-rated health status indicating that LBW individuals are more likely to report lower subjective health status but the coefficient is not significant. Second, we see positive and significant coefficient for mobility, showing that LBW individuals are more likely to have difficulties in activities of daily living by 4% points. Third, no coefficients are significant for depressive symptoms or impairment of cognitive ability.[8]

Table 6 reports the results of LBW impact on medical diagnosis. We see that most of the coefficients are positive and those for two diseases are significant. LBW individuals are more likely to suffer from hypertension or diabetes, which is consistent with previous findings from medical research (Endo et al. (2010) and Matsuda (2016)). Our results show that LBW is associated with about 8% or 12% higher probability to

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[8] In order to check robustness, we have also tested with the differently defined outcome variable. First, we changed the threshold from 16 to 20 in the CES-D score for depressive symptoms. Second, we used a simple sum of number of correct answers for each cognitive ability. Third, we computed Z-score for each ability standardized by age group of 10 years using whole sample for each area of cognitive ability. In all cases, estimation results were same as the main findings.

have these diseases by old age.[9]

Finally, Table 7 reports the results of LBW impact of Quality of Life (QOL). We see that the signs of the coefficients are all negative. In the case of the outcome variable "*life_satisfaction*," we see that the coefficient has small standard errors and the size is relatively large, showing that LBW individuals are less likely to report their life as a whole is good or very good by 15% points but the coefficient is not significant (p-value is 0.13). However, in general, we do not see statistical difference between LBW and non-LBW individuals.

In sum, at older ages, we do not detect evidence of negative LBW consequence on self-rated health, mental well-being, cognitive ability, or life satisfaction. Exceptions are that LBW is associated with higher risk of being diagnosed with diabetes or hypertension, and for having difficulties in mobility.

4. Discussions and additional analyses

We so far investigated LBW effects on childhood, adulthood, and old age outcomes. Although, generally, negative effects persist throughout one's life if an individual was born as a LBW baby, the adverse effects seem to be clear in childhood, seem to be smaller or fade out towards adulthood and in old age except for some difficulty in mobility and onset of hypertension or diabetes.

By field of outcome variables, we show adverse LBW effect in the childhood period but not in adulthood. Our findings on educational outcomes are consistent with the findings from Nakamuro, Uzuki and Inui (2013) that school performance in

[9] When we look at the age of diagnosis, the mean age of being diagnosed with hypertension (diabetes) for LBW individuals is 52 (57) years old, and 53 (55) years old for non-LBW individuals. In both cases, there is no difference in age of diagnosis. The results are omitted from the table to save space.

childhood is negatively affected by LBW, but the effect does not lead to significant difference in higher educational attainment. Although we need more evidence and objective variables of school performance, the Japan case appears to be similar to the U.S. case (Fletcher 2011), suggesting the adverse outcomes of early to medium-term education, but not of long-term (higher educational attainment). On the other hand, the Swedish case shows that high school completion is significantly higher for heavier babies (Bharadwaj, Lundborg and Rooth 2018) and the Taiwanese case shows that the number of years of schooling is greater for heavier babies (Xie, Chou and Liu 2016).

Turning to health outcome, our analysis shows statistical difference between LBW and non-LBW individuals in childhood health and some indicators of health in old age. Although our data set has a limited number of observations, the diagnosis of disease appears to exhibit the reliability of our data showing consistent results with medical literature such as in Endo et al. (2010) and Matsuda (2016). Our findings show that there are no differences between LBW and non-LBW in old age in terms of self-evaluated health and life satisfaction measures and cognitive skills, which are not yet well studied in the literature.

Overall, our findings are consistent with those in previous research that examined a part of life course LBW outcomes. While we provide the first evidence on a variety of life-course consequences of LBW in Japan, we make some reservations. First, our sample size is relatively small though it is hard to collect information on birth weight of older generations. A larger sample survey with objective information on birth weight would help us to explore the lifecycle effect of LBW. Second, we need to be careful about potential selection bias (or selective response) in our sample. Our data consists of responses by those who could actually answer the questionnaire about their childhood and birth weight.

As a similar issue to selective response, we have to take into account selective fertility and selective mortality during or soon after WWII to interpret our findings. That is, only people who were relatively wealthy and healthy could afford to have babies and only healthy babies have survived through these years. Fortunately, our data contains information regarding whether a respondent in Hiroshima was affected by radiation exposure by the atomic bombing in August 1945.[10] Our data contains small number of individuals whose parents were atomic bomb survivors although we do not have detailed clinical data on the severity of radiation exposure. However, it is worth examining whether the negative LBW effects are compounded if LBW babies are the children of atomic bomb survivors. Surviving through wartime is surely a traumatic experience, and it is easily expected that being exposed to atomic bombs is even more traumatic.[11] Hence, we include interaction terms of LBW and children of a mother who survived the atomic bomb and examine if the negative effects of LBW are exacerbated (we limit our sample to the babies born after the end of WWII in order to discriminate those who might have been exposed to atomic bomb during childhood).

Table 8 reports the results. We see that the interaction terms are statistically significant for self-rated health during childhood, educational attainment (*Atleas_high*, *Grad_high*), depression, and life satisfaction. The marginal effect is large at -0.325 for

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[10] The Radiation Effects Research Foundation (RERF), the successor of the Atomic Bomb Casualty Commission (ABCC), founded by the US National Academy of Sciences in 1947, has been conducting rigorous research on both short- and long-term health effects of radiation on atomic bomb survivors and their children. Despite the prediction that children of atomic bomb survivors would have higher propensity to suffer from mendelian and multifactorial genetic diseases, no clear epidemiological evidence has been found so far (Preston, Cullings, and Suyama 2008; Grant et al. 2015).

[11] Recent research on social determinants of newborn baby's health shows mothers who experienced natural disasters or stressful events are found to be at risk of giving birth to unhealthy babies (Lauderdale 2006; Currie 2013; Aizer, Stroud and Buka 2016).

childhood self-rated health status, -0.178 for highest educational attainment at least high school, -0.179 for high school graduates, and 0.323 for depressive symptoms. These observations imply that a LBW baby whose mother was an atomic bomb survivor is nearly 40% less likely to report their childhood health as good or very good, about 20% less likely to go to high school or graduate high school, and 35% higher chance of having symptoms of depression. While these additional analyses are only suggestive, the findings are important as it implies that when LBW is combined with another shock, the adverse effects will become even greater, and last into an old age.

5. Conclusion

We provide the first evidence on life course LBW effect in Japan. While we see a negative effect in health or school performance in the childhood period, the adverse effect is not detected in the adulthood period in terms of educational attainment and prime job status. Moreover, we cannot find a clear negative effect in terms of health, functional, or cognitive aspects or in terms of life satisfaction at older ages except for some difficulty in mobility and incidence of two specific diseases. In addition, we find that negative consequences on childhood self-rated health, higher educational attainment, and symptoms of depression could be exacerbated if mothers are affected by radiation exposure by the atomic bombing in Hiroshima.

Although our study has several limitations, we believe our research offers significant contributions by adding more evidence from Japan's case observing LBW effects on lifecycle for the first time in Japan. This is the first step to explore the LBW effect at each life stage, and further research with a larger sample size is desirable to confirm our results. Such efforts will contribute to uncover the mechanism of LBW on life events more precisely and provide evidence for effectiveness and timing of any policy intervention.

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Appendix Construction of main variables

Health_child: Respondents are asked to rate their past overall health status in childhood. The question is phrased: “Which of the following best describes your childhood health status?” Answer choices are given as 1: very good, 2: good, 3: neither good nor bad 4: bad, 5: very bad 6: changed over time. Then, our binary variable is created as 1: good or very good health and 0 otherwise.

Chronic_child: Respondents are asked to circle all the illnesses he/she has experienced from the list including 20 kinds of chronic illnesses from birth up to the age of 15. Our binary variable takes 1 if the respondent reported having one or more chronic illness during childhood and 0 otherwise. The illnesses included in the list are: infectious disease, polio, asthma, respiratory disease except asthma, allergy except asthma, severe diarrhea, meningitis / encephalitis, chronic ear problems, speech impairment (due to hearing loss), visual impairment, tuberculosis, severe headache (migraine), epilepsy/convulsion/seizure, mental illness, fracture/sprain, typhlitis, child diabetes, heart problem, leukemia or lymphoma, cancer/malignant (except mild skin cancer), others.

Japanese and *Math*: Respondents are asked to recall how well they have performed in (their native) Japanese language and mathematics at age 10 and rate their own performance. The question asks: “Please recall when you were age 10. How was your school record for Japanese language compared with your class mates?” Answer choices are given as 1: far better, 2: better, 3: about the same as other classmates, 4: worse 5: far worse 6: I was not attending a school. We exclude answer “6.” Our binary variable takes 1 if better or far better and 0 otherwise. For the questions asking about mathematics performance, the phrase is the same.

Atleast_high, *Grad_high*, *Atleast_uni* and *Grad_uni*: Respondents are asked to report their highest educational attainment using the following educational levels: (1) primary and middle school, (2) high school, (3) two-year college, (4) vocational training school (5) university (undergraduate), (6) university (post graduate, master course), and (7) university (post graduate, doctoral course). Moreover, respondents are asked whether they have graduated, dropped out, or are currently enrolled in that institution. We make several binary variables with different cut-offs: *Atleast_high* to take 1 for at least some high school education and 0 otherwise; *Grad_high* to take 1 for over high school graduates and 0 otherwise; *Atleast_uni* to take 1 for at least some university education and 0 otherwise; *Grad_uni* to take 1 for over university graduates and 0 otherwise.

Fulltime, Large_enterprise, and *Full_large_enterprise*: In the questionnaire respondents are asked several questions regarding their work status at age 54. Firstly they are asked if they were working at age 54. Then, if they were working, they are asked if they worked as a full-time worker or other types (part-time, etc.) In our data, more than 98% of male respondents answered that they were working; therefore, the variable of having a job does not give us enough variation. We create three binary variables: *Fulltime* to take 1 if the respondent was working full-time at an age of 54 and 0 otherwise; *Large_enterprise* to take 1 if the respondent was working at a larger enterprise (at least 300 employees) and 0 otherwise; *Full_large_enterprise* to take 1 if the respondent was working at a larger enterprise (at least 300 employees) as a full-time worker and 0 otherwise. We use the cut off of "at least 300 employees" according to the definition provided by the Small and Medium Enterprise Agency. Small and medium sized enterprise is defined according to type of industry. Because we do not have detailed information by industry, we use the definition of manufacturing industry in which more than 300 workers are considered as large enterprise (Small and Medium Enterprise Agency 2005). In *JSTAR*, the categorical variable does not allow us to be as precise, so we include 300 as large enterprise, as well. We use the definition of the manufacturing industry because it had on average the largest number of workers from 1976 to 2000 (Ministry of Health, Labour and Welfare http://www.mhlw.go.jp/wp/hakusyo/roudou/13/dl/13-1-4_02.pdf for industrial structure).

Health: Respondents are asked to rate their current overall health status. The question is phrased: "Please select the item that most accurately describes your overall current health," and choices are given as 1: very good, 2: good, 3: fairy good, 4: bad, 5: very bad, 6: don't know. Our binary variable takes 1 if good or very good health is reported and 0 otherwise.

Mobility: Respondents are asked if they were capable to conduct activities of daily living (ADL). ADL includes 10 activities: walk 100m, sit in a chair for two hours continuously, get up from a chair after sitting continuously for a long time, climb several flight of stairs without using the handrail, squat or kneel, raise your hands above your shoulders, push or pull a large object such as a living-room chair or sofa, lift and carry an object weighing 5kg or more, such as a bag of rice, pick up a small object such as a one-yen coin from a desktop with your fingers. Our binary variable takes 1 if the respondent reports difficulties in conducting any ADL activities and 0 otherwise.

Depression: Mental well-being is measured by using CES-D (The Center for Epidemiologic Studies Depression Scale). We construct a binary variable to take 1 if depressive symptoms are present (CES-D score >=16) and 0 otherwise (CES-D score<16). We use this cut off based on Shima (1985). This cut off is used widely in Japan's mental health literature.

Orientation_imp, Memory_imp, and *Numeracy_imp*: Respondents' cognitive ability is measured in three areas: orientation, memory, and numeracy. Orientation is measured by response to the request to state the year, month and day correctly of the survey date. We create a binary variable to take 1 if a respondent failed to state the date of the survey correctly (year, month, or day) and thus is regarded as impaired and 0 otherwise (*Orientation_imp*). Memory is measured by the task of recalling words. In this task, the surveyor reads out 10 simple words such as dog, knife, train, and so on. Then respondents are asked to recall them immediately after the list is read. We create a binary variable to take 1 if a respondent failed to recall more than 2 words and thus is regarded as impaired and 0 otherwise (*Memory_imp*). The numeracy test asks the respondents to conduct a simple arithmetic calculation only in his/her head. We create a binary variable to take 1 if a respondent failed in the first two questions and thus is regarded as impaired and 0 otherwise (*Numeracy_imp*). These first two questions are: "Please subtract seven from 100," and "Please subtract seven from that number." The cut off used here follows *JSTAR First Results 2009 Report* by Ichimura, Shimizutani and Hashimoto (2009). This cut off is used for international comparison because SHARE uses this cut off. In the questionnaire, there are two additional measurements. One is for orientation for location, and the other is late recall of the word. The latter indicator asks the respondent to recall the word not immediately after the surveyor has read out the words, but after the respondent has finished the whole cognitive ability related questionnaire. We do not use this due to larger number of missing data in comparison to other indicators.

Heart disease, Hypertension, Hyperlipidaemia, Stroke, Diabetes, Ulcer, Osteoporosis, Cataract, Urination, Dementia and *Cancer*: Respondents are asked if they were diagnosed with any of 20 specific diseases. We omit the diseases that have incidence under 1% among respondents. We create a binary variable for each diagnosis to take 1 if diagnosed and 0 otherwise. The diseases included are: heart disease, hypertension, hyperlipidaemia, stroke, diabetes, ulcer, osteoporosis, cataract, urination, dementia, and cancer.

life_satisfaction, *habitat_satisfaction*, *asset_satisfaction*, *family_satisfaction* and *leisure_satisfaction*: Respondents are asked to rate some aspects of life satisfaction in life as a whole, habitat, asset, family and leisure. The question is phrased as “Please answer degree of satisfaction for each item considered.” Response choices are given as: 1: satisfied, 2: satisfied to some extent, 3: slightly unsatisfied, 4: unsatisfied, 5: not applicable. Those who chose “5” are excluded. Our binary variables take 1 if a respondent reported he/she is satisfied or relatively satisfied in life as a whole (*life_satisfaction*), habitat (*habitat_satisfaction*), asset (*asset_satisfaction*), family (*family_satisfaction*), and leisure (*leisure_satisfaction*) and 0 otherwise.

Table 1 Descriptive statistics

	LBW babies			Non-LBW babies		
Variable	Observation	Mean	Std. Dev.	Observation	Mean	Std. Dev.
<Short-term outcome>						
Health_child	26	0.385	0.496	252	0.472	0.500
Chronic_child	26	0.538	0.508	252	0.484	0.501
Japanese	26	0.385	0.496	252	0.575	0.495
Math	26	0.346	0.485	252	0.496	0.501
<Medium-term outcome>						
Atleast_high	26	0.846	0.368	251	0.964	0.186
Grad_high	26	0.538	0.508	252	0.397	0.490
Atleast_uni	26	0.192	0.402	251	0.275	0.447
Grad_uni	26	0.192	0.402	252	0.270	0.445
Fulltime	26	0.654	0.485	252	0.484	0.501
Large_Enterprise	26	0.423	0.504	252	0.524	0.500
<Long-term outcome>						
Health	25	0.160	0.374	244	0.299	0.459
Mobility	25	0.120	0.332	244	0.070	0.255
Depression	22	0.273	0.456	221	0.176	0.382
Orientation_imp	25	0.080	0.277	244	0.016	0.127
Memory_imp	25	0.160	0.374	244	0.102	0.304
Numeracy_imp	25	0.160	0.374	243	0.115	0.320
Heart disease	25	0.080	0.277	244	0.045	0.208
Hyper-tension	25	0.400	0.500	244	0.275	0.447
Hyper-lipidaemia	25	0.040	0.200	244	0.119	0.324
Stroke	25	0.040	0.200	244	0.016	0.127
Diabetes	25	0.200	0.408	244	0.066	0.248
Ulcer	25	0.040	0.200	244	0.016	0.127
Osteo-porosis	25	0.080	0.277	244	0.025	0.155
Cataract	25	0.040	0.200	244	0.070	0.255
Ear disease	25	0.080	0.277	244	0.020	0.142
Urination	25	0.040	0.200	244	0.025	0.155
Dementia	25	0.040	0.200	244	0.020	0.142
Cancer	25	0.040	0.200	244	0.020	0.142
life_satisfaction	25	0.760	0.436	244	0.898	0.304
habitat_satisfaction	25	0.840	0.374	244	0.848	0.359
asset_satisfaction	25	0.600	0.500	244	0.643	0.480
family_satisfaction	25	0.800	0.408	244	0.902	0.298
leisure_satisfaction	25	0.720	0.458	244	0.840	0.367
<Covariates>						
Sex (1: male 0: female)	25	0.480	0.510	244	0.406	0.492
Highest education received: Highschool	25	0.640	0.490	244	0.693	0.462
Highest education received: University	25	0.200	0.408	244	0.246	0.432
Highest education received: Postgraduates	25	0.000	0.000	244	0.029	0.167
Owning house (1: Owened house with land, 0: otherwise)	25	0.920	0.277	244	0.906	0.293
Respondent's age	25	65.040	6.711	244	63.336	6.627
Currently smoking (in 2015) (1: smoking, 0:not smoking)	25	0.240	0.436	244	0.127	0.334
Smoked in the past (1: smoked, 0: not smoked)	25	0.280	0.458	244	0.262	0.441
Birth (1: Born before the end of WWII 0: otherwise)	25	0.240	0.436	244	0.217	0.413
SES	25	20.937	17.047	244	66.760	342.594

Table 2　LBW Effects on health and school performance during childhood

	Health		School performance	
	Health_child	*Chronic_child*	*Japanese*	*Math*
LBW	-0.063	0.071*	-0.191***	-0.127**
	(0.055)	(0.011)	(0.003)	(0.004)
Observations	278	278	278	278
R-squared	0.02	0.03	0.03	0.04

Standard errors are clustered at city level. *** p<0.01, ** p<0.05, * p<0.1

Covariates are not shown for brevity.

Table 3　LBW Effects on educational attainment

	Education			
	Atleast_high	*Grad_high*	*Atleast_uni*	*Grad_uni*
LBW	-0.096	-0.095	-0.075	-0.068
	(0.026)	(0.030)	(0.039)	(0.052)
Observations	277	277	277	277
R-squared	0.06	0.04	0.26	0.23

Standard errors are clustered at city level. *** p<0.01, ** p<0.05, * p<0.1

Covariates are not shown for brevity.

Table 4　LBW Effects on employment situation at an age of 54

	Working status at an age of 54		
	Fulltime	*Large_enterprise*	*Full_large_enterprise*
LBW	0.179	-0.101	-0.014
	(0.051)	(0.031)	(0.023)
Observations	268	268	268
R-squared	0.26	0.09	0.17

Standard errors are clustered at city level. *** p<0.01, ** p<0.05, * p<0.1

Covariates are not shown for brevity.

Table 5 LBW Effects on health, mortality, depression and cognitive ability

	Health	*Mobility*	*Depression*	Impairment of cognitive ability		
				Orientation _imp	*Memory_ imp*	*Numeracy_ imp*
LBW	-0.108	0.036**	0.098	0.059	0.028	0.013
	(0.042)	(0.001)	(0.053)	(0.025)	(0.137)	(0.077)
Observations	269	269	243	269	269	268
R-squared	0.05	0.07	0.07	0.04	0.08	0.09

Standard errors are clustered at city level. *** p<0.01, ** p<0.05, * p<0.1
Covariates are not shown for brevity.

Table 6 LBW Effects on onset of diseases

	Heart disease	*Hyper-tension*	*Hyper-lipidaemia*	*Stroke*	*Diabetes*	*Ulcer*
LBW	0.012	0.082***	-0.054	0.008	0.121**	0.022
	(0.034)	(0.001)	(0.015)	(0.032)	(0.005)	(0.020)
Observations	269	269	269	269	269	269
R-squared	0.05	0.09	0.04	0.04	0.08	0.04

Standard errors are clustered at city level. *** p<0.01, ** p<0.05, * p<0.1
Covariates are not shown for brevity.

	Osteo-porosis	*Cataract*	*Ear disease*	*Urination*	*Dementia*	*Cancer*
LBW	0.040	-0.042	0.066	0.014	0.024	0.015
	(0.015)	(0.010)	(0.029)	(0.021)	(0.013)	(0.009)
Observations	269	269	269	269	269	269
R-squared	0.07	0.03	0.08	0.03	0.04	0.05

Standard errors are clustered at city level. *** p<0.01, ** p<0.05, * p<0.1
Covariates are not shown for brevity.

Table 7 LBW Effect on life satisfaction

	Life satisfaction				
	life_ satisfaction	*habitat_ satisfaction*	*asset_ satisfaction*	*family_ satisfaction*	*leisure_ satisfaction*
LBW	-0.149	-0.058	-0.007	-0.120	-0.150
	(0.032)	(0.035)	(0.063)	(0.063)	(0.037)
Observations	269	269	269	269	269
R-squared	0.06	0.05	0.08	0.06	0.05

Standard errors are clustered at city level. *** p<0.01, ** p<0.05, * p<0.1
Covariates are not shown for brevity.

Table 8　Confounding effect by atomic bomb exposure

	Short-term outcomes				Medium-term outcomes						
	Health		School performance		Education				Working status		
	Health_child	*Chronic_child*	*Japanese*	*Math*	*Atleast_high*	*Grad_high*	*Atleast_uni*	*Grad_uni*	*Fulltime*	*Large_ enterprise*	*Full_large_en terprise*
LBW	-0.075	0.077	-0.178	-0.069	-0.032	-0.028	-0.096	-0.084	-0.101	0.183	-0.000
	(0.033)	(0.080)	(0.069)	(0.109)	(0.015)	(0.022)	(0.051)	(0.054)	(0.096)	(0.100)	(0.099)
Mother exposed to atomic bomb	-0.064*	0.021	-0.054**	-0.050*	0.005	0.006	0.002	-0.013***	0.204*	0.347	0.283
	(0.005)	(0.005)	(0.002)	(0.006)	(0.002)	(0.004)	(0.001)	(0.000)	(0.025)	(0.088)	(0.078)
LBW ×Mother exposed to atomic bomb	-0.325*	0.249	-0.100	-0.107	-0.178*	-0.179*	-0.094	-0.064	0.099	-0.236*	0.026
	(0.036)	(0.113)	(0.192)	(0.179)	(0.017)	(0.020)	(0.105)	(0.100)	(0.180)	(0.033)	(0.146)
No. of Obs.	216	216	216	216	216	216	216	216	209	209	209
R-Squared	0.03	0.05	0.03	0.02	0.04	0.03	0.27	0.26	0.12	0.26	0.20

Standard errors are clustered at city level. *** p<0.01, ** p<0.05, * p<0.1
Covariates are not shown for brevity.

	Long-term outcomes										
Health				Impairment of cognitive ability			Life satisfaction				
	Health	*Mobility*	*Depression*	*Orientation _imp*	*Memory_ imp*	*Numeracy_ imp*	*life_ satisfaction*	*habitat_ satisfaction*	*asset_ satisfaction*	*family_ satisfaction*	*leisure_ satisfaction*
LBW	0.004	-0.082	0.030	0.058	0.059	0.172	-0.025	-0.088	-0.060	0.002	-0.053
	(0.059)	(0.037)	(0.029)	(0.021)	(0.098)	(0.092)	(0.033)	(0.039)	(0.060)	(0.050)	(0.047)
Mother exposed to atomic bomb	-0.038	-0.011	-0.043**	0.015	0.085**	0.065*	0.002	-0.015	-0.041	0.116*	-0.059
	(0.020)	(0.011)	(0.002)	(0.005)	(0.007)	(0.009)	(0.013)	(0.024)	(0.028)	(0.010)	(0.017)
LBW ×Mother exposed to atomic bomb	-0.207	0.209	0.323**	-0.087	-0.232	-0.362	-0.220	0.114*	0.426**	-0.284*	-0.107
	(0.116)	(0.055)	(0.007)	(0.016)	(0.077)	(0.066)	(0.045)	(0.013)	(0.010)	(0.044)	(0.076)
No. of Obs.	210	210	191	210	210	209	210	210	210	210	210
R-Squared	0.05	0.09	0.07	0.04	0.08	0.14	0.06	0.08	0.10	0.06	0.07

Standard errors are clustered at city level. *** p<0.01, ** p<0.05, * p<0.1
Covariates are not shown for brevity.