RIETI Discussion Paper Series 13-E-035

The Effects of Birth Weight: Does fetal origin really matter for long-run outcomes?

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RIETI Discussion Paper Series 13-E-035
April 2013

The Effects of Birth Weight: Does fetal origin really matter for long-run outcomes? [1]

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Abstract

This paper investigates whether birth weight itself *causes* individuals' future life chances. By using a sample of twins in Japan and controlling for the potential effects of genes and family backgrounds, we examine the effect of birth weight on later educational and economic outcomes. The most important finding is that birth weight has a causal effect on academic achievement at around the age of 15, but not on the highest years of schooling and earnings.

Keywords: Birth weight, Nutritional intake, Identical twins, Endogeneity
JEL classification codes: I10, I20

[1] This study was conducted as part of a project titled "Research on Measuring Productivity in the Service Industries and Identifying the Driving Factors for Productivity Growth" of the Research Institute of Economy, Trade, and Industry (RIETI). We gratefully acknowledge that this research was financially supported by Grant-in-Aid for Scientific Research (A) titled "The Assessments of the Quality and the Productivity of Non-marketable Services" (Research Representative: Takeshi Hiromatsu, No. 3243044).
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Introduction

It would be generally better to have a small baby at birth and then raise him/her to grow big later in life – this has long been believed to be good practice in child-bearing in Japan. Before C-section delivery or other obstetric procedures became popular throughout society, people perhaps aimed to reduce the risk of endangering mothers' lives by giving birth to a small baby. This widespread belief seems to be still dominant today. However, it is unexpectedly little known that there is a hidden risk of having a small baby: recent research has found that low birth weight is significantly associated with both short- and long-run adult outcomes, such as infant mortality, student achievements, and adulthood health (Conley & Bennett (2000); Linnet et al (2006); Currie & Hyson (1999), etc.).

Why is this happening? Low birth weight is caused by preterm delivery or low fetal growth that may reflect variation in nutritional intake in the womb. Low-birth weight is thus recognized as the leading indicator of poor health among infants, which may delay brain and somatic development and then affect a wide range of subsequent outcomes later in life. This mechanism has been also rapidly revealed as an object of epigenetics (e.g., Petronis, 2010 etc.). Like the results drawn from data in U.S., Denmark and England, Kohara & Ohtake (2009) used official statistics from the Vital Statistics and the National Assessment of Academic Ability in Japan and found a negative correlation between birth weight and academic achievements measured by standardized test scores in G6 and G9 at the prefecture level. If this is the case, can there be any doubt that the Government of Japan must shape a policy agenda to increase the birth weight of new born babies, for example, through improvements in the health of pregnant mothers? Unfortunately, however, there is no simple answer to this question.

While much is known about the cross-sectional correlation between birth weight and adulthood outcomes, little is known regarding the extent to what would have happen to an individual outcome if a person who was actually born with a heavier birth weight had been born with a lighter birth weight. In other words, it is highly possible that observed differences in birth weights among new-born infants may simply reflect unobserved parental characteristics which are also correlated with adulthood outcomes of an individual: a selection bias arises when part of individual outcomes can be explained by unobserved parental characteristics. Observed correlations using cross-sectional data in previous literature thus did not provide a full description of the effect of birth weight and result in biased and inconsistent estimates.

In this research, we would like to answer the questions of whether birth weight itself *causes* individuals' adulthood outcomes later on in life. Causality is thus obviously the key. One of the innovative methods that social scientists have employed in recent years address the causal relationship between birth weight and adulthood outcomes is to use a sample of twins (or sometimes siblings). In fact, many economists, such as Berhman & Rosenzweig (2004), Royer (2009), Almond et al (2005) for the U.S., Miller et al (2005) for Australia; Lawlor et al (2006) for Scotland; Oreopoulos et al (2006) for Canada, and Black et al (2007) for Norway (see Currie (2009) for a more comprehensive survey) use a dataset containing information on twin-pairs and attempt to cope with the problem of unobserved differences in ability and family environments. These considerable efforts have been dedicated to uncovering the effect of birth weight on adulthood outcomes: previous research reached a consensus that birth weight does matter both in the short- and long-run.

We also follow this approach to deal with the aforementioned bias, comparing the differences between twin-pairs to isolate the pure effect of birth weight on the adulthood outcomes, holding innate abilities and family environments constant. Another advantage of using a sample of twins is that, because twin pairs have the same gestation length, the differences in birth weight between twins are attributed solely to differences in fetal growth rates. The main research question of interest in this paper is thus: does nutrition intake in utero really matter for one's life chance? If so, which stage of one's life is the most affected?

To the best of our knowledge, the case of Japan is relatively unexplored due to the data limitation. This is unfortunate given the recent variable findings in Japan that low birth weight is associated with parental socioeconomic factors, such as the mother's smoking habits and employment status (Tsukamoto et al, 2007; Kawaguchi & Noguchi, 2012b etc.). The understanding of whether an individual inherits his/her parental socioeconomic status at fetal origin would contribute to further discussion of the intergenerational transmission mechanism of social stratification, to which policy circles may pay considerable attention. In this study, we take advantage of the unique twins-datasets that the authors have collected in Japan through a web-based survey.

To answer our research question, we follow the protocol of previous literature and outline a twin-fixed effect strategy using a sample of monozygotic twins (hereafter, MZ twins) who are genetically identical. However, interestingly, there is a variation in birth weight between twin-pairs in general. As pointed out by Ashenfelter and Rouse (1998), first-born twins are usually heavier than their second-born siblings at birth. This setting allows us to create a counterfactual situation of what would have happened to adulthood outcomes of a pair of twin who were born with a lower birth weight if s/he had been born with a heavier birth weight instead. We then set up five main outcomes to be examined: (i) participation in private (or national) middle schools; (ii) student performance at the age of around 15; (iii) ranking at the college attended; (iv) years of schooling; and (v) earnings. The significant finding in this paper is that birth weight only causes academic achievement under the age of 15. Unlike some of the evidence from western countries, this effect subsequently disappears. Our empirical results show that fetal growth may affect student performance in young children, but it does not directly affect his/her adulthood outcomes in later life, such as educational attainments and earnings.

The rest of this paper is organized as follows: the next section reviews relevant literature to sort out information on what we still do not know and explains how we tackled the methodological problems in previous research. The following sections introduce the empirical specifications to be estimated, identify the potential bias emerging in the econometric analysis, and determine the analytical techniques to be used to identify the causal impact of birth weight on adulthood outcome later in life. Then in the final section, we describe the unique twins dataset used for empirical analysis and present the empirical results.

Relevant Literature

Evidence to show whether and to what extent increasing the birth weight of newborn infants can improve their future life chances would be useful for framing an appropriate policy direction regarding the nutritional intake of expectant mothers. A growing body of research has attempted to identify the causal effects of birth weight on not only short-term but also long-term outcomes by the use of twin data. Such data enables researchers to rule out the potential influences of genetic makeup and family backgrounds that affect both birth weight and later outcomes and to obtain better estimates of the causal effects of birth weight than those derived from conventional cross-sectional analysis. In this section, we review the relevant literature investigating the causal effect of birth weight on educational and economic outcomes, in particular by using twin data.

Regarding educational outcomes, there is evidence based on twin studies that birth weight has a long-term impact. Behrman and Rosenzweig (2004), Black et al. (2005) and Oreopoulos et al. (2008), using twin data from Minnesota, Norway and Manitoba, respectively, found that birth weight has a positive effect on high school completion. Lin and Liu (2009) analyzed Taiwanese twin data and found that birth weight increased grades at age 15. It is noteworthy that Behrman and Rosenzweig (2004) and Lin and Liu (2009) showed that the OLS coefficients for birth weight without controlling for genes and family backgrounds are underestimated by 50%, while Black et al. (2005) found that OLS estimates and twin-fixed effects are similar in size. Behrman and Rosenzweig (2004) and Lin and Liu (2009) argue that their findings suggest that parents may invest more in lighter twins to make up for their developmental disadvantage.

However, some studies suggest that the effect of birth weight on years of schooling is rather small (Royer, 2009) or that there is no significant relationship between birth weight and educational attainment or cognitive ability measured by language test scores (Miller et al., 2005; Oreopoulos et al., 2008). It remains unclear whether this mixed evidence is due to differences in measures regarding educational outcomes or data sources.

There is relatively less evidence on the direct effect of birth weight on economic outcomes. Miller et al. (2005) are one of the exceptional groups of researchers who found a positive, direct effect of birth weight on earnings, but argue that birth weight plays only a minor role in determining earnings, with each additional ounce of birth weight increasing earnings by 0.4%. Other studies that examine the effect of birth weight on economic outcomes include Royer (2009) and Oreopoulos et al. (2008). However, Royer (2009) did not find evidence to show that birth weight is associated with neighborhood income levels in adulthood. Although Oreopoulos et al. (2008) found that birth weight affects social assistance takeup and length in adulthood, but given that they also found the effect of birth weight on high school completion, it is unclear whether the birth weight effect on economic outcomes would remain after controlling for the mediating effect of educational outcomes.

In Japan, no research has used twin data to investigate the causal effect of birth weight on educational and economic outcomes in adulthood. The most important reference work is a non-twin study conducted by Kawaguchi and

Noguchi (2012b), analyzing early childhood data from the Longitudinal Survey of Babies in the 21st Century. They found that low birth weight, defined as a weight below 2,500 grams, is associated with a delay in development at age two and a half, but not with behaviors at age six and a half. A possible reason for the association disappearing at an older age may be the fact that Japanese parents invest more in their children if their development is observed to be slow at an earlier stage. Therefore, this evidence does not confirm whether the birth weight effect remains only for a short period of time in Japan. Furthermore, little is known about the effect of birth weight on much later educational and economic outcomes in Japan.

We aim to further the literature by using Japanese twin data to bring out new findings in the following three respects. Firstly and most importantly, we will estimate the effects of birth weight by addressing, for the first time in Japan, potential endogeneity biases due to the effects on birth weight, post-natal development and later outcomes of genes and parental behaviors usually associated with a family's socio-economic status. Secondly, we will investigate longer-term educational and economic outcomes as has been done in relevant previous research in Japan, which may lead to insight into how long-lasting the birth weight effects would be. Lastly, we will examine educational outcomes measured in several ways for the same sample, which may contribute to clarifying which educational outcomes should be highlighted, given the current mixed evidence across the world on the effects of birth weight on educational outcomes.

Empirical Settings

In order to address our research questions of how birth weight affects adulthood outcomes, we begin the analysis using a conventional OLS to report the cross-sectional correlations with the entire twin sample, in which many prior studies have found that the birth weight is strongly associated with a wide range of adulthood outcomes. Following the previous literature, we outline the simple education production function illustrating the input-output relationship at home or school that particularly highlights the role of child health. The model can be formally expressed in the following mathematical equation where y is outcomes and is a function of the birth weight (bw) and unobservables (A), such as genetic makeup or maternal/pre-natal care in combination with other characteristics (X) and random disturbance with mean zero and constant variance (e) as specified in the equation (1) and (2) below. Note that the first-born twin is denoted as 1 by a subscript and the second-born as 2.

$$y_{1j} = A_{1j} + \beta bw_{1j} + X_{1j}'\gamma + e_{1j} \quad (1)$$
$$y_{2j} = A_{2j} + \beta bw_{2j} + X_{2j}'\gamma + e_{2j} \quad (2)$$

The coefficient of β refers to the effect of the birth weight on outcome variables holding other observed characteristics constant. As we discussed earlier, the cross-sectional estimate of β may be biased and inconsistent because unobservables, A_{ij}, affect both the birth weight and outcomes. However, identical twins enable us to set up $A_{1j}=A_{2j}$, given that they share genetic makeup and family environments. We will thus take a twin fixed effect approach taking the difference between equation (1) and (2) to obtain a within-twin fixed effects estimate of β, yielding:

$$(y_{1j} - y_{2j}) = \beta(bw_{1j} - bw_{2j}) + (X_{1j} - X_{2j})\gamma + (e_{1j} - e_{2j}) \quad (3)$$

In equation (3), unobservable, A_j, is eliminated, relieving us of the concern that the outcomes are partly explained by individual unobserved characteristics. Given the assumption that the error term is an idiosyncratic, which is independent of all other terms in the equation, β is considered as the consistent estimate.

Data

The data used for our empirical analysis was collected through a web-based survey in Japan between the months of February and March 2012 (see Nakamuro & Inui (2012) for more detailed information on the data collection strategy). We conducted the survey through a web-based survey company, Rakuten Research, with over 2.2 million monitors. In order to analyze the effect of birth weight on adulthood outcomes, our sample targeted twins who are non-students between the ages of 20 and 60. Through this web-based survey, one member of a twin pair is responsible for reporting regarding him/herself and his/her twin sibling at one time, and the results are designed differently from those of the other twin survey filled out by both members of the twin pair[3].

[3] One may question that, in our survey, there may exist substantial measurement errors in self-reported birth weight and other outcomes by *one* of the twin pairs, instead of *both*. It is important to note that we have 23 twin pairs, each member of which was included in this survey. When we check their responses, we find out that their responses reported by each

Once the monitor(s) filled out the questionnaires, they would be given a certain amount of cash-equivalent "points" that could be spent on Rakuten online shopping. In order to exclude "fake" twins, who pretend to be twins to collect the cash-equivalent points, we carefully developed the following data collection strategy: we did not inform respondents that the purpose of our survey was to collect data from twins. Furthermore, we started with five questions on family and siblings that were not related to twin status and then, in the sixth question, for the first time, asked whether or not a respondent was a twin. If the respondent answered "No" in this question, s/he would be automatically excluded from the survey. We discovered 23 twin pairs, each member of which was included in this survey, then thoroughly checked the responses of both twins, and eliminated one of the twins randomly from our sample. Our web-based survey overcame the disadvantages of the data collection in previous literature, such as small sample size or data attrition. Consequently, we collected 2,360 complete pairs of twins (4,720 individuals) while 1,371 twin pairs (2,742 individuals) are monozygotic (see Table 1). To the best of our knowledge, this is one of the largest databases of twins compiled in Japan nationwide, and it conveys a wide range of socioeconomic information.

Variables

The independent variable of interest is, of course, birth weight for which we set up several variants in the following way: the primary measure is the birth weight which is self-reported by one of the twin-pair. The response category in the original questionnaire ranged from 1 (= less than 1,500 grams) to 7 (= more than 4,500 grams) and 8 (=don't know). We set the minimum to 1,500 and the maximum to 4,500 grams. Then we took the mid-value for the categories between 2 (=1,750 grams) and 7 (= 4,250 grams). Based on this variable, we create two variants of the key independent variables: a variant is the natural logarithm of the

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other are quite accurate: the correlations between self-reported and cross-reported birth weight is 91.2%. Not only the birth weight but also other outcomes show over 90% of correlations. Furthermore, we check whether there exist significant differences between responses on him/herself and on his/her twin siblings; for example, one may be doubtful that respondents are prone to pretend that their earnings or education are higher than those of their twin siblings. However, according to the result drawn from two sample t-tests for difference of the means, there is no difference between them. As a further robustness check, we include a respondent dummy in all specifications, but the dummies are statistically insignificant.

birth weight. The other is defined as a dichotomous variable measuring the low birth weight, coded as 1 if the birth weight is more than 2,500 grams and zero otherwise.

The descriptive statistics summarized in Table 2 show that the average twins in our sample weighed 2,441 grams at birth and more than half of them were categorized as infants with low birth weights. As suggested in previous literature, our data illustrates a disparity in birth weight between the first and second born of twins: the average birth weight of the first born is 2,464 grams while that of the second born is 2,423 grams, and this difference is statistically significant at a 5% level. Furthermore, our data shows that 24.8% of MZ twin pairs were different in weight at birth, which is crucially important to ensure an accurate estimate of the twin fixed effects model. If we restrict the sample to those who are MZ twins, we have quite similar results (see Table 1-a). We run separate regressions for each variant of the birth weight: the explanatory power assessed by R^2 statistics from within twin fixed-effects estimations helps us to choose the best possible option among these three variants of birth weight, as presented in Table 3.

We then characterize six outcomes ranging from the period of childhood to adulthood. The first outcome variable is a type of middle school attended, which aims to measure scholastic ability in early childhood. Some twelve-year-old children enroll in Japan private junior high schools instead of public schools because most private junior high schools require children to pass entrance examinations, which are often competitive and selective. According to the School Basic Survey administered by Ministry of Education, Culture, Sports, Science and Technology, the enrollment rate of private junior high schools was 8%[4] in 2012, with a considerable geographical variation. While the majority of children and parents do not consider choosing private schools at all, a non-negligible proportion of children and parents in Japan have recognized the entrance examinations of private junior high schools as the first screening process through educational institutions. In our survey, we ask which type of middle school the respondent and his/her twin siblings attended. 17.1% of respondents were students of private and national junior high schools, which is slightly higher than the percentage showed by official statistics nationwide. This may in part be due to the characteristic of our survey that it is more likely to gather information from residents in large

[4] This number includes the enrollment rate of national junior high schools. National junior high schools are government-owned junior high schools, mostly affiliated with national universities. These schools also require applicants to pass entrance examinations to enroll.

metropolitan areas, such as Tokyo and Osaka. Moreover, 10.9% of MZ twins-pairs attended different types of school: for example, one attended a private school and the other a public school. The second outcome variable is student performance at middle school, which is measured on a 5 point-scale (1=lower; 2=below average; 3=average; 4=above average; 5=upper) based on a subjective evaluation of respondents' and their twin-siblings' academic achievements.

The third outcome is the ranking of the college attended with a restricted sample of college-educated respondents. Our survey asks the name of the high school where respondents and their twin siblings graduated. We convert this information into a measure of deviation value ("hensachi" in Japanese), which represents the ranking of each educational institution with a mean of 50 and standard deviation of 10 by using a series of deviation values. We match the name of colleges/universities and the deviation value of each department of each college/university by using the dataset, "Kawaijuku College Rankings", calculated and released in 2011 by Kawaijuku, one of the largest cram schools in Japan. College admissions in Japan are determined almost entirely by performance in written examinations administered by each institution except for some special admission programs, such as athletic scholarship programs.

The fourth outcome is years of schooling. To avoid the possibility of institutional misreporting, in our original questionnaire, we list every type and level of educational institution (26 categories, including "don't know"), and then ask respondents to select the highest degree obtained. The choice of "dropout or stopped" was inserted between the questions on each type and level of institution in order to disentangle cases of leaving school without a diploma. In calculating the years of education, we assume that those who "dropped out" or "stopped" finished half of the minimum required years to complete the educational institution last attended (e.g., drop out from high school = 10.5 years of schooling).

It is important to note that our data shows that the within-twin variations in educational experiences become larger with the passage of time: only 5.9% or 10.9% of twin pairs attended different types of schools when they were primary or middle school students. Eventually, 38.4% of twin pairs in our sample acquired different numbers of years of education. Some may wonder why twins, who share the same genetic makeup and family environment, eventually end up so differently in terms of educational backgrounds. Bound and Solon (1999) and Neumark (1999) pointed out that even if the within-twin estimate is able to remove the effect of genetic endowment, it does not necessarily mean that the within-twin estimate completely eliminates all aspects of ability bias to the extent that ability goes beyond genes. The potential endogeneity could be caused by unobserved differences in ability between twin-pairs which may result from different experiences in earlier childhood. However, according to our survey, parents are unlikely to treat twins differently, particularly in terms of educational investment. For example, there is little difference in experiences of shadow education between twin-pairs, which may be a crucial part of household expenditures on education in Japan[5]. Our survey shows that the within-twin variations in shadow education is quite small, as the within-twin variations in formal education become larger with the passage of time (see Table 1-b). Therefore, it can be said that within-twin variations do not reflect any systematic difference in the parental educational strategy for each twin, which often leads to different experiences in earlier childhood.

The fifth outcome is labor market performance measured by the natural logarithm of annual wage before tax deductions during the 2010 fiscal year[6]. The response category in the original questionnaire ranged from 1 (=no income) through 16 (=more than 15 million JPY). We set the minimum (1=no income and 2=less than 0.5 million JPY) to zero and maximum (16=more than 15 million JPY) to 15 million JPY. Then, we take the mid value for categories between 3 (=0.5 million-0.99 million JPY) and 15 (=10 million-14.99 million JPY).

Empirical Results

Table 4 presents the results estimated by a conventional OLS to replicate the correlational studies in previous literature. Regardless of the variant of dependent variables, birth weights are strongly associated with adulthood outcomes, except for the type of middle school and ranking of college attended. The results coupled with the positive coefficients suggest that birth weight affects the majority of educational outcomes later in life, such as student performance at the age of around 15 and the highest years of schooling, as well as the labor market

[5] According to the official statistics of the Ministry of Education, Culture, Sports, Science and Technology, a large part of household expenditures on education has been spent on shadow education in Japan. The Benesse Educational Research and Development Center showed in 2009 that approximately 20% of elementary and high school students and 50% of junior high school students accessed shadow education, such as cram schools or prep schools.

[6] This survey asked about earnings during the fiscal year of 2010, instead of 2011, because earnings during the fiscal year of 2011 could have been affected by the Great East Japan Earthquake that occurred on March 11, 2011.

outcome measured by annual earnings. The effect seems quite large: for example, an extra 100 grams in birth weight raises earnings in the labor market by 5.3% on average. Taken as a whole, our results are consistent with the mainstream of previous literature showing a positive correlation between birth weight and adulthood outcomes.

Then we analyze the effect of birth weight on adulthood outcomes concerning whether the difference in weight at birth is substantial or reflects the fact that infants with lighter birth weights fundamentally differ from those of their counterparts with heavier birth weights. As explained earlier, we employ the twin-fixed effects to compare the differences between MZ twins to isolate the pure effect of birth weight on the adulthood outcomes, holding innate abilities and family environments constant. Table 5 shows a quite different story from conventional OLS estimates. The effect of the birth weight on the adulthood outcomes in the longer run, such as the highest years of education and earnings, appears to be statistically insignificant across models. However, the effect still remains in education: birth weight causes academic achievement at the age of around 15. It may also cause the probability of passing a private junior high school and the ranking of college in which they participated, although the evidence to support this is weak. The twin-fixed effects estimates are substantially larger than the cross-sectional ones.

This paper has thus succeeded in answering the research question. Like the evidence generated from western countries, our finding also suggest that birth weight affects educational outcomes, particularly student performance at the age of around 15. On the other hand, the effect is not long-lasting, and birth weight does not affect longer-run outcomes, such as the highest years of schooling and earnings. Strictly speaking, in this sense, birth weight itself is not the culprit with respect to the more disadvantaged adulthood outcomes.

Conclusion

This paper has investigated the question of whether the effects of birth weight on later educational and economic outcomes, if any, are causal. By using data from a sample of twins in Japan, we have provided best available estimates for the causal effects of birth weight on academic achievement at the age of around 15. We would be rather cautious about concluding that birth weight does not affect longer-run outcomes, such as highest years of schooling and earnings. Future research should examine whether this is also the case where educational attainment measured by educational qualifications obtained, or where earnings are measured with smaller measurement errors than with self-reported earnings.

Given that the most plausible factor affecting birth weight differences between MZ twins is intrauterine nutrient intake, our findings suggest that improving pregnant mothers' nutrient intake may lead to the improvement of educational outcomes at age 15, thereby improving future life chances. Kawaguchi and Noguchi (2012a) argued that the decrease in the average birth weight between 1990 and 2005 could be partly explained by medical instructions offered to pregnant mothers. This implies that increasing birth weight through improving pregnant mothers' nutrient intake would be policy-relevant.

In order to bring out more detailed and solid implications to policy, future research needs to test whether the findings of this paper based on a twin sample can be generalized to non-twin populations. It is also necessary to investigate for whom increasing birth weight is most effective in improving future life chances, for instance, by detecting at which point in the birth weight distribution the effect of birth weight is strongest.

Table 1: Sample Collected through Web-Based Survey

MZ Twins	DZ Twins	Don't Know
2,742 (1,371 pairs)	1,764 (882 pairs)	214 (107 pairs)

(Source) Authors' calculations

Table 1-a: Differences in Educational Outcomes between Twin-Pairs

	Birth weights	Private primary school	Private middle school	Highest years of education
Total	24.8%	5.9%	7.5%	38.4%
MZ Twins	21.0%	5.6%	7.1%	32.0%
DZ Twins	32.1%	6.5%	7.7%	48.8%

Table 1-b: Differences in Educational Expenditure on Shadow Education between Twin-Pairs

	Preschool	Primary school	Middle school	High school
Total	2.4%	4.1%	6.2%	6.5%
MZ Twins	1.6%	3.1%	4.7%	4.6%
DZ Twins	3.2%	5.8%	9.0%	9.0%

(Note) 1. Shadow education represents access to prep schools, private tutoring, and distance learning.
2. Private primary and middle schools are including national schools.

(Source) Authors' calculations

Table 2: Descriptive Statistics

	Whole Sample		MZ Twins	
	Mean	STDV	Mean	STDV
Dependent Variables:				
Birth weight	2,441.00	564.87	2413.76	551.51
Log (birth weight)	7.77	0.23	7.76	0.23
Non-LBW (1 >2,500 grams)	0.45	0.50	0.50	0.50
Independent Variables:				
Type of junior high school (1=private or national)	0.171	0.376	0.16	0.37
Student performance at the age of 15	2.57	1.10	2.60	1.08
Ranking of college attended	52.00	9.84	51.72	9.76
Years of schooling	14.38	2.33	14.42	2.30
Log (earnings)	5.96	0.74	5.98	0.74

(Source) Authors’ calculations

Table 3: Goodness of Fit

Dependent \ Independent	Private Middle School	Student Performance (Age 15)	Ranking College	Highest Years of Schooling	Earnings
Birth weight	0.0060	0.0052	0.0061	0.0002	0.0013
Log (birth weight)	0.0054	**0.0070**	0.0057	0.0001	**0.0016**
Non-LBW	**0.0075**	0.0014	**0.0194**	**0.0008**	0.0006

(Source) Authors' calculations

Table 4: Empirical Results (OLS)

Independent \ Dependent	Private Middle School	Student Performance (Age 15)	Ranking College	Highest Years of Schooling	Earnings
Birth weight (/100)	0.011 (0.016)	0.063* (0.032)	0.091 (0.442)	0. 291*** (0.066)	0.053*** (0.017)
Log (birth weight)	0.016 (0.038)	0.140* (0.079)	0.178 (1.082)	0.810*** (0.167)	0.122*** (0.043)
Non-LBW	-0.001 (0.017)	0.035 (0.035)	0.542 (0.517)	0.206** (0.070)	0.035* (0.019)
Observations	1,998	3,577	1,470	3,631	2,785

(Note) 1. The numbers in parentheses are heteroskedasticity-robust standard errors.
2. ***, **, and * represent 1%, 5%, and 10% significance level, respectively.
3. Other independent variables are (a) private middle school: gender, father's education; (b) student performance: gender, father's education, living standard at the age of around 15; (c) ranking of college: the same with (b); (d) highest years of schooling: the same with (b); (e) log (earnings): age, age squared, gender, father's education, living standard at the age of around 15, highest years of schooling, marital status, years of tenure at the current employment, hours of work per day. Most of the control variables are statistically significant. The full results are available upon request.

(Source) Authors' calculations

Table 5: Empirical Results (Twin-Fixed Effects)

Dependent / Independent	Private Middle School	Student Performance (Age 15)	Ranking College	Highest Years of Schooling	Earnings
Birth weight	0.050*	0.210*	3.138	-0.077	0.065
(/100)	(0.029)	(0.108)	(3.090)	(0.170)	(0.071)
Log (birth weight)	0.112*	**0.575****	7.326	-0.137	**0.177**
	(0.066)	**(0.249)**	(7.149)	(0.417)	**(0.161)**
Non-LBW	**0.053***	0.099	**5.659***	**-0.146**	-0.042
	(0.030)	(0.088)	**(3.055)**	**(0.162)**	(0.072)
Observations	1,257	2,206	918	2,234	1,832
# of twin pairs	(641)	(1,138)	(736)	(1,144)	(1,032)

(Note) 1. The numbers in parentheses are heteroskedasticity-robust standard errors and clustering at the family level.
2. ***, **, and * represent 1%, 5%, and 10% significance level, respectively.

(Source) Authors' calculations

Reference

Almond, D., Chay, K. Y. & Lee, D. S. (2005). The costs of low birth weight. *Quarterly Journal of Economics*, 120(3), 1031-1083.

Black, S. E., Devereux, P. J. & Salvanes, K. G. (2007). From the cradle to the labor market? The effect of birth weight on adult outcomes. *Quarterly Journal of Economics*, 122(1), 409-439.

Behrman, J. R. & Rosenzweig, M. R. (2004). Returns to birthweight. *Review of Economics and Statistics*, 86(2), 586-601.

Blickstein, I. & Kalish, R. B. (2003). Birthweight discordance in multiple pregnancy. *Twin Research*, 6(6), 526-531.

Bound, J. & Solon, G. (1999). Double trouble: on the value of twins-based estimation of the return to schooling. *Economics of Education Review*, 18 (2), 169-182.

Conley, D. & Bennett, N. G. (2000). Is Biology destiny? birth weight and life chances. *American Sociological Review*, 65(3), 458-467.

Currie, J. (2009). Healthy, wealthy, and wise: socioeconomic status, poor health in childhood, and human capital development. *Journal of Economic Literature*, 47(1), 87-122.

Currie, J. & Hyson, R. (1999). Is the impact of health shocks cushioned by socioeconomic status? the case of low birthweight. *American Economic Review*, 89(2), 245-250.

Kanjuku (2011). Zenkoku koukou chuugaku hensachi souran [A comprehensive list of the deviation values of Japan's high- and junior high schools].

Kawaijuku (2011). Kawaijuku hensachi ranking [The ranking of colleges]. Retrieved Feb 15, 2013 from http://daigaku.jyuken-goukaku.com/nyuushi-hensati-ranking/kawaijyuku/

Kawaguchi, D. & Noguchi, H. (2012a). Shinseiji no taiju ha naze gensho shiteiru noka [Why has birth weight decreased?]. Ihori, T., Kaneko, Y. & Noguchi, H. eds. *Aratana risuku to shakaihosho: shogai wo tsujita shiensaku no kochiku [New risks and social security]*, University of Tokyo Press, 17-33.

Kawaguchi, D. & Noguchi, H. (2012b). Teitaijyu shussei: genin to kiketsu [The low birth weight: the cause and the consequence]. *Global COE Hi-Stat Discussion Paper Series*, 265.

Kohara, M. & Ohtake, F. (2009). Kodomo no kyouiku seika no kettei youin [The determinants of educational outcomes of a child]. *The Japanese Journal of*

Labour Studies, 588, 67-84.

Lawlor, D., Clark, H., Smith, G. D., & Leon, D. (2006). Intrauterine growth and intelligence within sibling pairs: findings from the Aberdeen children of the 1950s Cohort. *Pediatrics*, 117(5), 894-902.

Lin, M. & Liu, J. (2009). Do lower birth weight babies have lower grades? : Twin Fixed effect and instrumental variable method evidence from Taiwan. Social Science & Medicine, 68, 1780-1787.

Linnet, K. M., Wisborg, K., Agerbo, E., Secher, N. J., Thomsen, P. H. & Henriksen, T. B. (2006). Gestational age, birth weight, and the risk of hyperkinetic disorder. *Archives of Disease in Childhood*, 91(8), 655-660.

Miller, P., Mulvey, C. & Martin, N. (2005). Birth weight and schooling and earnings: estimates from a sample of twins, *Economics Letters*, 86, 387-392.

Nakamuro, M. & Tomohiko, I. (2012). Estimating the returns to education using the sample of twins; the case of Japan. *RIETI Discussion Paper Series*, 12-E-076.

Neumark, D. (1999). Biases in twin estimates of the return to schooling. *Economics of Education Review*, 18 (2), 143-148.

Oreopoulos, P., Stabile, M., Walld, L. & Roos, L. L. (2008). Short-, medium-, and long-term consequences of poor infant health: an analysis using siblings and twins. *Journal of Human Resources*, 43(1), 88-138.

Petronis, A. (2010). Epigenetics as a unifying principle in the aetiology of complex traits and diseases. Nature, 465, 721-777.

Tsukamoto, H., Fukuoka, H., Koyasu, M., Nagai, Y. & Takimoto, H. (2007). Risk factors for small for gestational age. *Pediatrics International*, 49(6), 985-990.

Royer, H. (2009). Separated at girth: U.S. twin estimates of the effects of birth weight, *Applied Economics*, 1(1), 49-85.