Yamane and Tsutsui *BMC Pregnancy and Childbirth* (2025) 25:382
https://doi.org/10.1186/s12884-025-07477-4

BMC Pregnancy and Childbirth

RESEARCH

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Non-linear association of low birthweight with risk factors including women's BMI: evidence from an international comparison

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Abstract

Background It is widely known that, in addition to physical characteristics such as parents' height and weight, social attributes such as parents' education, income level, and employment status have a significant impact on birthweight. However, these results were obtained using data from individual countries, and there were no country-level comparisons of the factors identified as influencing birthweight. A multi-country analysis is essential to determine whether these factors are consistently linked to low birthweight across different economic and healthcare systems.

Methods Using panel data on low-birthweight fertility rates for 143 countries over the period of 2000–2015, we used five factors (women's body mass index [BMI], real gross domestic product [GDP] per capita, women's employment status, healthcare level, and adolescent childbearing) in relation to countries' low-birthweight rates to determine how these factors relate to each country's low-birthweight rate and estimate a fixed-effects model. Considering the possibility that these five factors are non-linear rather than linear, we estimated quadratic and cubic functions. We conducted a detailed analysis of women's BMI and real GDP per capita. Furthermore, we considered the 2008 global financial crisis as an exogenous natural experiment for the low-birthweight rate and conducted a difference-in-differences (DID) analysis to confirm the possibility that the correlation between women's employment rate and low-birthweight rate is a causal relationship.

Results All five factors were identified as important risk factors. Of the five, all but adolescent childbearing were found to have a non-linear rather than a monotonous linear relationship with low birthweight. The low-birthweight rate improved sharply with improvement in women's average BMI below 28. Furthermore, the results of the DID analysis suggest that women's employment plays an important role in the relationship between low-birthweight rates and GDP.

Conclusions These results provide a useful policy tool for achieving the goal of the 65th World Health Assembly to "reduce the incidence of low birthweight." In particular, improvements in women's average BMI, real GDP per capita, and women's employment rates in low-income countries may be linked to reductions in the incidence of low birthweight.

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Keywords Low birthweight, Non-linear associations, Women's body mass index, Per capita GDP, Women's employment status, Difference-in-differences, Healthcare, Adolescent childbearing

Background

Birthweight is an indicator of infant health that influences later life. Barker and Osmond (1986) [1] and Barker (1990) [2] found that low birthweight was significantly and negatively associated with adult health. Recent studies in the social sciences have established that birthweight has significant negative effects on social attributes, such as income and occupation, in addition to adult health [3–5]. Moreover, high birthweight is significantly negatively associated with adult health [6, 7]. Furthermore, analysis of Japan, the U.S., and India Yamane and Tsutsui (2022) [8] showed that low and high birthweight matter to quality of life. Their study demonstrated that the associations between birthweight and quality of life are widely diverse across countries depending on economic status.

The determinants of low birthweight include parental smoking, alcohol and drug use, employment status, age at birth, maternal pre-pregnancy emaciation tendency, preterm delivery, and psychological stress during pregnancy [9–12]. Economic studies have reported that parents' physical characteristics, mothers' years of education, and fathers' socioeconomic status (education, income, occupation, etc.) are risk factors for low birthweight [4].

How well do the factors found in intra-country studies explain low-birthweight rates in each country? This is the research question addressed in the present study. In affluent countries, a fetus has a higher probability of being born healthy because the mother is likely to be well nourished and the medical system is well equipped to handle the risks of childbirth. However, the opposite may be true in poor countries. In May 2012, the 65th World Health Assembly set a goal of a 30% reduction in the low birthweight rate between 2012 and 2025; however, as of 2015, the goal is far from being achieved.[1]

Exploring the factors associated with low birthweight through international comparisons is important to overcome this situation [13]. This study investigates whether the critical factors of low birthweight that have been identified with intra-nation data can also be confirmed using international data. International comparative studies are important to identify policy issues that should be addressed nationally. Despite its importance, to the best of our knowledge, no international comparative study has been conducted to examine the determinants of low birthweight. This study addressed these gaps.

In this study, we considered that women's BMI may be an important factor in low birth weight. We hypothesize that the probability of having a low-birthweight infant is lower in countries with higher BMI levels and that poorer countries have a higher percentage of low-birthweight infants because of their poor sanitation and healthcare systems. Maternal obesity is primarily associated with macrosomia (large-for-gestational-age infants) rather than with low birthweight in general. However, if the average BMI of women in a country becomes too high, the percentage of infants with low birthweight may increase due to pregnancy complications, such as pre-eclampsia and placental dysfunction [14]. Thus, BMI is indirectly associated with low birth weight through these complications. In addition, when the level of medical care becomes very high, it helps ensure that low-weight fetuses are born safely. If this is the case, the low-birthweight rate will have a U-shaped relationship with BMI and income level. Furthermore, this study considers employment status and average mother's age at childbirth as important factors for low birthweight.

To test these hypotheses, this study used data collected from 143 countries, spanning 2000–2015, which Blencowe et al. [13] collected. We estimated fixed-effects models to control for unobservable variables, such as race and cultural background. To derive policy implications through international comparisons, the results should suggest causes rather than associations. In this case, estimating fixed-effects models using panel data has certain merit compared to cross-sectional analysis because it reveals the rule of within-individual time variation. In addition, we conducted a difference-in-differences (DID) analysis using the 2008 global financial crisis as an exogenous natural experiment. To the best of our knowledge, there are no studies on low birthweight using DID analysis, although the impact of the global financial crisis on fertility, health, and healthcare systems has been studied [15, 16]. Furthermore, whereas most of these studies are country-by-country comparisons of European countries, this study analyzed 143 countries, both developing and developed.[2]

The remainder of this paper is organized as follows: Sect. 2 proposes the hypotheses, presents the definitions

[1] Comparing 2012 and 2020 using the latest available low birthweight ratio for 32 countries of OECD data (https://stats.oecd.org/index.aspx?queryid=30118#), 21 countries have seen a decrease (-10.04% on average), while the remaining 11 countries have seen an increase (10.76% on average). Overall, it will be difficult to achieve the 30% reduction goal for these 32 countries.

[2] Matysiak et al. [15] showed how changes in labor market conditions and economic growth affected fertility rates before and after the Great Recession in Europe by using data from 251 regions in 28 European Union member countries. Hessel et al. [16] showed how the financial crisis has affected subjective health status in Greece and Ireland. In addition to these studies, numerous other studies have examined the impact of the global financial crisis on healthcare systems in European regions [25, 26].

of the variables used in this study, and explains the methods of analysis. Section 3 presents the empirical results. Section 4 discusses the results and concludes the paper.

Methods

Hypotheses

According to [17], having a BMI either lower or higher than the standard, which ranges from 18.5 to 24.99, is undesirable for health. Thus, we hypothesized that women with a standard BMI would have a lower probability of delivering low-birthweight infants. In particular, thin women are more likely to give birth to underweight infants due to undernutrition and other reasons [18]. Thus, we hypothesized the following:

> *Hypothesis 1 The low-birthweight rate decreases, though diminishingly, as women's average BMI for the respective country increases and may have a U-shaped curve with respect to the average BMI of women.*

As countries with a low real GDP per capita have poor nutritional status and healthcare systems, they are more likely to fall ill when their health deteriorates [19]. Thus, the low-birthweight rate is expected to be higher in poorer countries. This situation improves as countries become richer but to a diminishing degree. Therefore, we propose the following hypothesis:

> *Hypothesis 2 The low-birthweight rate is higher in countries with lower real GDP per capita. However, the degree of the decline diminishes.*

Many other factors may be involved in the probability of low birthweight [10, 11, 13, 20]. This study addresses women's employment status, level of medical care, and mother's age at birth.

Regarding employment status, we use women's employment rate and vulnerable employment rate, refers to women's work in their family-operated small businesses.[3] Vulnerable employment is more prevalent in poorer countries, and as societies mature, women shift to regular businesses. Though we imagine that harder work generally raises the low-birthweight rate, it is difficult to ascertain the effect of the shift from "vulnerable employment" to "employment." Therefore, this study does not have a priori expectations but examines the data to ascertain the reality.

All else being equal, a society with a well-developed healthcare system keeps mothers in good health and reduces the prevalence of low-birthweight infants. However, as medical technology becomes more highly developed, more lives will be saved, but the probability of low-birthweight infants is likely to increase. Therefore, we propose the following hypothesis:

> *Hypothesis 3.1 Countries with higher levels of medical care have lower rates of low-birthweight babies because they can maintain maternal health. However, in countries with more advanced medical technology, the decline in the incidence of low birthweight is progressively diminishing because babies that would have otherwise been stillborn are saved.*

There is an appropriate age for giving birth; adolescent childbearing, which is more common in poor countries, is considered too early, whereas childbearing for those over 40 years old, which is more common in rich countries, is considered too late [21–23].[4] Because only adolescent fertility rates are available, we posit the following hypothesis:

> *Hypothesis 3.2 Countries with a higher percentage of adolescent (teenage) births have a higher incidence of low birthweight.*

Method of estimation

Definitions of all variables used in this study are given in Table 1.

To test these hypotheses, we estimated the quadratic and cubic equations with respect to *BMI* and *GDP*.

$$\begin{aligned} R_{LBW\,it} &= \alpha_1 BMI_{it} + \alpha_2 BMI^2{}_{it} + \alpha_3 BMI^3{}_{it} + \beta_1 GDP_{it} \\ &+ \beta_2 GDP^2{}_{it} + \beta_3 GDP^3{}_{it} + \gamma_1 EMPLOYEE_{it} \\ &+ \gamma_2 WEAK\_LABOR_{it} + \gamma_3 Medicine_{it} + \gamma_4 YOUNG\_MOTHER_{it} \\ &+ \sum_{k=2001}^{2015} \delta_k DYEAR_t^k + u_i + \varepsilon_{it},\ t = 2000, \ldots, 2015 \end{aligned} \tag{1}$$

Where u_i is the fixed effect of the ith country, $DYEAR_t^k$ is the year *k*'s dummy variable, and ϵ_{it} is the disturbance term. In the estimation of the quadratic function, where α_3 and β_3 are assumed to be 0, if the estimate of α_1 is significantly negative and the estimate of α_2 is significantly positive, then *R_LBW* is a U-shaped function of *BMI*, consistent with Hypothesis 1. Similarly, if β_1 is significantly negative and β_2 is significantly positive, then *R_LBW* is a U-shaped function of *GDP*, consistent with Hypothesis 2. To determine the curve estimated by the

[3] We distinguish the status in women's employment between two variables of total employed: (a) wage and salaried workers, self-employed workers, and self-employed workers with employees and (b) self-employed workers with no employees, members of producers' cooperatives, and contributing family workers. We define (a) as employment rate and (b) vulnerable employment rate. Women's employment rate is defined here by excluding vulnerable employment.

[4] The number of adolescent births per 1,000 girls aged 15–19 is 229 in the Central African Republic and 210 in Niger, more than 20% of the total number of births [27].

Table 1 Variable definitions and sources

Variable	Definition	Source
R_LBW	Number of newborns weighing less than 2,500 g divided by the total number of live births (%)	WB UNICEF
BMI	Mean of the body mass index (BMI) of women (kg/m^2)	WHO
GDP	Real GDP per capita (US$)	PWT
EMPLOYEE	Number of female wage and salaried workers, self-employed workers, and self-employed workers with employees divided by female working-age population (%)	WB
WEAK_LABOR	Number of female own-account workers and contributing family workers divided by total female employment (%)	WB
BIRTH_STAFF	Births attended by skilled health staff divided by total births (%)	WB
YOUNG_MOTHER	Proportion of births among adolescent mothers aged 15–19 (%)	WB

WB stands for the World Bank Open Data (https://data.worldbank.org), and PWT for the Penn World Table (https://www.rug.nl/ggdc/productivity/pwt/?lang=en). We used age-adjusted mean BMI data available from the WHO Data Bank (https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/body-mass-index). The differences in sample sizes across variables are due to data availability constraints in the original sources, as some countries did not consistently report certain indicators

cubic function, we draw a curve of the fitted value of *R_LBW* using the quadratic and cubic functions and examine whether its shape is consistent with Hypotheses 1 and 2. If γ_1 ad γ_3 are significantly negative and γ_2 and γ_4 are significantly positive, then Hypotheses 3 1 and 3 2 are supported, respectively.

All analyses were conducted using Stata. For the fixed-effects model, we accounted for within-country correlation over time by clustering standard errors at the country level.

This study reports the results using a fixed-effects model with the advantage of controlling for unobservable and fixed factors during the observation period, including racial, ethnic, and cultural backgrounds unique to each country. Another important merit is that it reveals within-country rules, and its estimation results may reflect a causal relationship.[5]

In addition, this study applies a DID analysis to further confirm the causal relationships for policy implications [24]. An important exogenous event in the low-birthweight rate worldwide was the 2008 financial crisis. Therefore, this study uses 2008–2009 as the event period and tests whether changes in the low-birthweight rate from before to after the event significantly differed among countries that experienced a large decline in real GDP during this period (treatment group) and those that did not (control group).[6] Therefore, we estimated Eq. (2).

$$\begin{aligned} R\_LBW_{it} = {} & \delta_1 GROUP_i + \delta_2 AFTER_t + \delta_3 (GROUP_i \times AFTER_t) \\ & + \lambda_1 EMPLOYEE_{it} + \lambda_2 WEAK\_LABOR_{it} \\ & + \lambda_3 BIRTH\_STAFF_{it} + \lambda_4 YOUNG\_MOTHER_{it} + u_i + \varepsilon_{it} \end{aligned} \tag{2}$$

where *AFTER* is a dummy variable coded as 1 for 2009 and later, and 0 for 2007 and earlier. *GROUP* is a dummy variable coded as 1 when the sum of real GDP growth in 2008 and 2009 is in the bottom 50% (treatment) and 0 when it is in the top 50% (control). The coefficient δ_3 of *GROUP*×*AFTER* ≡ *CROSS* indicates the impact of the financial crisis.

For the DID analysis, we implemented an interaction-based approach, ensuring that standard errors were also clustered at the country level for robustness.

$$\frac{\partial^2 R\_LBW_{it}}{\partial\, GROUP_i \partial\, AFTER_t} = \delta_3 \tag{3}$$

If δ_3 is significantly positive, it supports the interpretation that the negative association between GDP and LBW suggests a causal relationship.

We further estimate Eq. (4) to test whether the global financial crisis affected the low- birthweight rate through the employment rate.

$$\begin{aligned} R\_LBW_{it} = {} & \delta_1 GROUP_i + \delta_2 AFTER_t \\ & + \delta_4 EMPLOYEE_{it} \times GROUP_i \\ & + \delta_5 AFTER_t \times EMPLOYEE_{it} + \delta_7 EMPLOYEE_{it}^2 \times GROUP_i \\ & + \delta_8 AFTER_t \times EMPLOYEE_{it} \\ & + \left(\delta_3 + \delta_6 EMPLOYEE_{it} + \delta_9 EMPLOYEE_{it}^2\right) \times (GROUP_i \times AFTER_t) \\ & + + \lambda_1 EMPLOYEE_{it} + \lambda_2 WEAK\_LABOR_{it} + \lambda_3 BIRTH\_STAFF_{it} \\ & + \lambda_4 YOUNG\_MOTHER_{it} + u_i + \varepsilon_{it} \end{aligned} \tag{4}$$

In this case,

$$\frac{\partial^2 R\_LBW_{it}}{\partial\, GROUP_i \partial\, AFTER_t} = \delta_3 + \delta_6 EMPLOYEE_{it} + \delta_9 EMPLOYEE_{it}^2 \tag{5}$$

where δ_3 represents the impact of the financial crisis on *R_LBW* through channels other than $EMPLOYEE$, and $\delta_6 EMPLOYEE_{i,t} + \delta_9 EMPLOYEE_{it}^2$ represents the impact through changes in $EMPLOYEE$.

Results

Our dataset consists of a maximum of 2,145 country-year observations from 143 countries for the period 2000–2015 (see Table S1 in the Supplementary Material for the

[5] In contrast, the between-country effect model is unlikely to reflect any causal relationship because it only shows differences between two countries.

[6] [26] and [16] also used DID to compare people's health in Greece and Ireland before and after the global financial crisis with other countries [28]. used DID to examine whether the impact of the global financial crisis on income inequality differs between developed and emerging economies across 70 countries.

Table 2 Descriptive statistics of the variables

	Low-income countries			Middle-income countries			High-income countries		
	n	median	IQR	*n*	median	IQR	*n*	median	IQR
R_LBW	42	14.44	6.28	55	8.68	5.65	46	7.16	3.04
BMI	42	23.40	2.70	55	26.1	1.50	46	25.8	1.40
GDP	42	2405	2181	55	10,361	6721	42	35,203	17,963
EMPLOYEE	42	9.55	12.66	54	26.44	12.23	44	44.14	12.75
WEAK_LABOR	42	81.44	25.87	54	30.04	29.48	44	6.87	5.96
BIRTH_STAFF	42	70.65	38.7	55	98.8	4.80	42	99.5	1.20
YOUNG_MOTHER	42	9.35	6.01	55	4.31	4.89	45	1.32	1.36

Low-income countries were defined as those with a mean GDP of $5893 or less, middle-income countries as those with a mean GDP between $5893 and $18,411, and high-income countries as those with a mean GDP of $18,411 or more. The differences in sample sizes across variables are due to data availability constraints in the original sources, as some countries did not consistently report certain indicators

Table 3 Correlation coefficients between Low-birthweight rate and the key variables

	R_LBW		
	Low-income countries	Middle-income countries	High-income countries
BMI	-0.48***	0.03	0.39***
GDP	-0.23***	-0.17***	0.12***
EMPLOYEE	-0.46***	-0.29***	-0.41***
WEAK_LABOR	0.43***	0.11***	0.27***
BIRTH_STAFF	-0.79***	-0.37***	-0.30***
YOUNG_MOTHER	0.29***	0.44***	0.59***

Refer to the Table 2 footnote. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

list of countries). However, the number of observations varies by variable owing to data availability constraints, with the minimum number of observations being 1,304.

Descriptive statistics

Table 2 presents the descriptive statistics for the variables used in the estimation. First, we defined "low-income countries" as the bottom 30%, "middle-income countries" as the mid- 40%, and "high-income countries" as the top 40% based on the average GDP for 2000–2015. The median rate of low birthweight decreased as GDP increased. The median BMI was lowest in low-income countries but did not differ between middle- and high-income countries.

Preliminary analysis

Table 3 presents the correlation coefficients between *R_LBW* and key variables. In the low-income countries, *R_LBW* and *BMI* were negatively correlated at the 1% level, whereas in the high-income countries, they were significantly positively correlated. Similarly, *R_LBW* and *GDP* are significantly negative at the 1% level for the low- and middle-income countries but significantly positive at the 1% level for the high-income countries. Regardless of country affluence, *R_LBW* correlates negatively with the female employment rate (*EMPLOYEE*) and *BIRTH_STAFF* but positively with vulnerable employment (*WEAK_LABOR*) and *YOUNG_MOTHER* (adolescent fertility rate). Simple correlations were consistent with our hypotheses.

Figure 1 shows the means of *R_LBW* and *BMI* for the entire world as well as for low-income, middle-income, and high-income countries. In the low-income countries, *R_LBW* declined substantially, by 2% in the 16 years examined, whereas it declined only slightly in the middle-income countries, and it even rose, though not significantly, in the high-income countries. In aggregate, it has declined slightly worldwide. Moreover, *BMI* increased significantly not only in low-income countries but also in middle- and high-income countries. An increase in *BMI* in low-income countries is regarded as an improvement in --health, whereas in middle- and high-income countries, it may indicate the opposite.

Main result

Table 4 presents the estimation results for Eq. (1). Column (1) shows the estimates of the quadratic function of *BMI* and *GDP*. The estimate of *BMI* was significantly negative, and that of the squared term was significantly positive, indicating a U-shaped curve. However, the bottom of the U-curve was 28.83, indicating that most observations were in the decreasing domain. In contrast, the estimates on *GDP* and GDP^2 were insignificant. The estimates of *EMPLOYEE* and $EMPLOYEE^2$ were significantly positive and negative, respectively, indicating an inverse U-shape with a peak at 41%, which is close to the median of *EMPLOYEE* for high-income countries (Table 2). *WEAK_LABOR* and its squared values were not significant. *BIRTH_STAFF* and its square were significantly negative and positive, respectively, indicating a U-shape with a bottom at 74.7%. *YOUNG_MOTHER* was significantly positive. These results support our hypotheses, with the exception of Hypothesis 2.

To examine whether Hypothesis 2 is valid, columns (2) and (3) present the results in the case that the *BMI* and *GDP* variables are included separately. In column (3), the estimates of *GDP* and GDP^2 become significantly negative and positive, respectively, which is consistent with Hypothesis 2. Column (4) presents the estimates

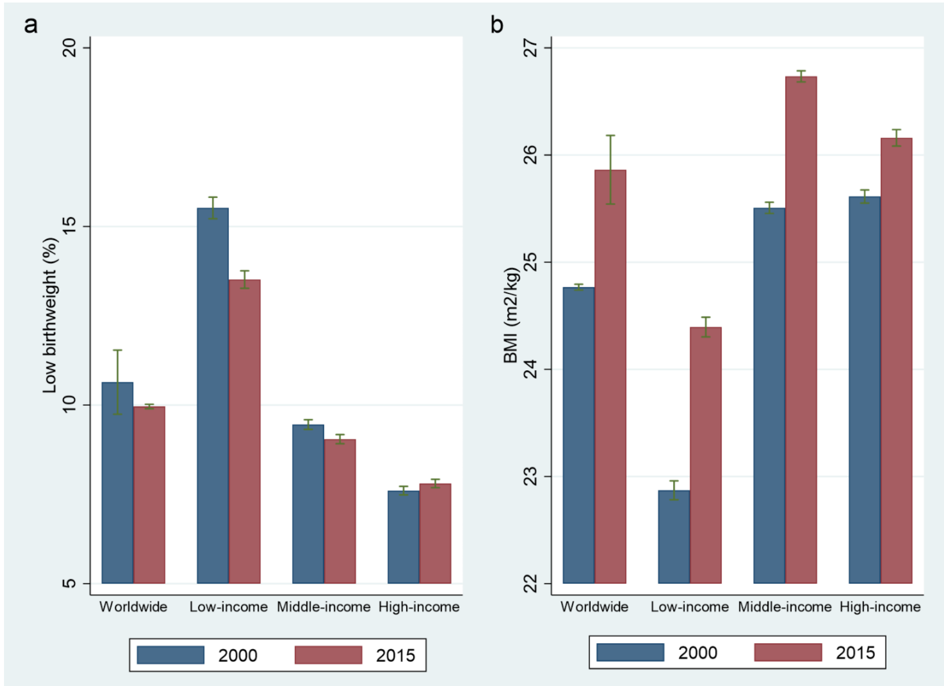

Fig. 1 Worldwide changes in low birthweight and BMI from 2000 to 2015. Error bars indicate the standard error of the mean (SEM)

of the cubic function of *BMI* and *GDP*. The estimates are qualitatively the same as those in column (1), except that *BIRTH_STAFF* and $BIRTH\_STAFF^2$ become insignificant. The estimate of BMI^3 was significantly negative. Figure 2 shows the predicted values of *R_LBW* calculated from the estimates in columns (1) and (4) of Table 4, which are overlaid on the scatter plots of *R_LBW* and *BMI*. The curve of the quadratic function is U-shaped, whereas the curve of the cubic function reveals that *R_LBW* decreases strongly until the inflection point at 26.7 and then decreases gradually thereafter. However, the two curves are fairly similar; the only qualitative difference is that the quadratic function predicts an increase in *R_LBW* after the bottom, that is, $BMI = 28.8$, and the cubic function predicts a decrease.[7]

To further evaluate the model's predictive performance, Supplementary Figure S1 compares the actual and predicted low-birthweight rates. The correlation between them is 0.63, significant at the 1% level.

Examination of causality: DID analysis

We first checked whether the parallel trend assumption holds true. Figure 3a presents the average *R_LBW* values for the treatment and control groups, which show that there was no extreme difference in the movements of the two groups before the onset of the 2008 financial crisis. Figure 3b and c illustrate the groups separately to enlarge the figure and show the movement more clearly. However, the *R_LBW* of the control group was not affected by the crisis (Fig. 3b). The *R_LBW* of the treatment group increased during the crisis for a period of time. These figures reveal that the financial crisis was an exogenous event to *R_LBW*, affecting only the treatment countries, and that the assumption of a parallel trend was satisfied.

To further confirm the plausibility of the DID approach, we examined employment rate trends for treatment and control groups (Fig. 4). The observed patterns indicate that employment rates followed similar trends before 2008, supporting the assumption that any post-crisis divergence is attributable to the financial shock rather than pre-existing differences.

Columns (1) and (2) of Table 5 present the estimation results of Eq. (2). When *R_LBW* is regressed on the three variables *AFTER*, *GROUP*, and *CROSS* ($= GROUP \times AFTER$), *CROSS* is significantly positive at the 1% level, indicating that countries hit harder by the financial crisis have a lower low-birthweight rate than those that were not (column 1). In column (2), when *EMPLOYEE* and $EMPLOYEE^2$ were added, *CROSS* was significantly positive at the 5% level.

Columns (3) and (4) present the estimation results of Eq. (4). Column (3) presents the results when only *EMPLOYEE* and $EMPLOYEE^2$ were included in *CONTROL*. Column (4) presents the results of the full specification of the control variable as in column (1) of Table 4. The coefficients of $CROSS \times EMPLOYEE$ and $CROSS \times EMPLOYEE^2$ are significantly positive and

[7] Though this discrepancy occurred in a small domain, it might become important in the future when *BMI* will be even higher.

Table 4 Estimation results of Eq. (1)

VARIABLES	(1)	(2)	(3)	(4)
BMI	-5.299***	-5.909***		-48.13***
	(1.745)	(1.853)		(14.87)
BMI^2	0.0919***	0.102***		1.795***
	(0.0320)	(0.0341)		(0.576)
BMI^3				-0.0224***
				(0.00742)
lnGDP	-2.311		-4.734**	-2.442
	(1.762)		(1.998)	(7.990)
lnGDP^2	0.111		0.235**	0.148
	(0.0960)		(0.107)	(0.892)
lnGDP^3				-0.00221
				(0.0331)
EMPLOYEE	0.0820*	0.0860**	0.0914**	0.0922**
	(0.0431)	(0.0426)	(0.0407)	(0.0376)
EMPLOYEE2	-0.00130**	-0.00132**	-0.00130**	-0.00127***
	(0.000566)	(0.000573)	(0.000500)	(0.000452)
WEAK_LABOR	-0.00678	-0.00828	-0.0167	0.0156
	(0.0255)	(0.0243)	(0.0260)	(0.0242)
WEAK_LABOR^2	0.000269	0.000337	0.000482	0.000131
	(0.000364)	(0.000341)	(0.000361)	(0.000319)
BIRHT_STAFF	-0.0523**	-0.0534**	-0.0863**	-0.0211
	(0.0211)	(0.0214)	(0.0355)	(0.0193)
BIRTH_STAFF^2	0.000350**	0.000336**	0.000537**	0.000136
	(0.000163)	(0.000159)	(0.000264)	(0.000143)
YOUNG_MOTHER	0.2785***	0.2288***	0.3318***	0.2235***
	(0.0735)	(0.0720)	(0.0729)	(0.0706)
D_year2000	-0.771***	-0.671***	-0.386**	-0.740***
	(0.242)	(0.208)	(0.186)	(0.231)
D_year2001	-0.725***	-0.618***	-0.411**	-0.694***
	(0.210)	(0.181)	(0.159)	(0.202)
D_year2002	-0.661***	-0.561***	-0.399***	-0.643***
	(0.200)	(0.170)	(0.151)	(0.190)
D_year2003	-0.639***	-0.554***	-0.386**	-0.619***
	(0.188)	(0.162)	(0.149)	(0.180)
D_year2004	-0.536***	-0.466***	-0.337***	-0.520***
	(0.168)	(0.145)	(0.128)	(0.159)
D_year2005	-0.513***	-0.462***	-0.342***	-0.495***
	(0.155)	(0.137)	(0.120)	(0.149)
D_year2006	-0.434***	-0.394***	-0.274***	-0.427***
	(0.135)	(0.120)	(0.102)	(0.132)
D_year2007	-0.357***	-0.330***	-0.231**	-0.354***
	(0.120)	(0.109)	(0.0886)	(0.119)
D_year2008	-0.322***	-0.299***	-0.214***	-0.321***
	(0.108)	(0.0998)	(0.0792)	(0.107)
D_year2009	-0.290***	-0.263***	-0.209***	-0.295***
	(0.104)	(0.0912)	(0.0795)	(0.101)
D_year2010	-0.251***	-0.234***	-0.196***	-0.246***
	(0.0901)	(0.0827)	(0.0710)	(0.0883)
D_year2011	-0.202***	-0.196***	-0.157***	-0.189**
	(0.0743)	(0.0725)	(0.0589)	(0.0737)
D_year2012	-0.125**	-0.121**	-0.0991**	-0.132**
	(0.0614)	(0.0611)	(0.0496)	(0.0613)
D_year2013	-0.114**	-0.117**	-0.116**	-0.120**

Table 4 (continued)

VARIABLES	(1)	(2)	(3)	(4)
	(0.0456)	(0.0466)	(0.0465)	(0.0477)
D_year2014	-0.0490	-0.0488	-0.0767*	-0.0401
	(0.0359)	(0.0355)	(0.0416)	(0.0374)
Constant	94.94***	92.38***	32.62***	450.2***
	(25.43)	(25.40)	(9.990)	(123.0)
Observations	1,388	1,423	1,394	1,388
R-squared	0.467	0.453	0.387	0.528
Number of countries	133	136	134	133

R_LBW is the dependent variable. The estimation method used was a fixed effects model. *YEAR* dummies are included in the estimation but are not shown here to save space. Robust standard errors are indicated in parentheses. All analyses were conducted using *Stata*, and standard errors were clustered at the country level to account for within-country correlation over time. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

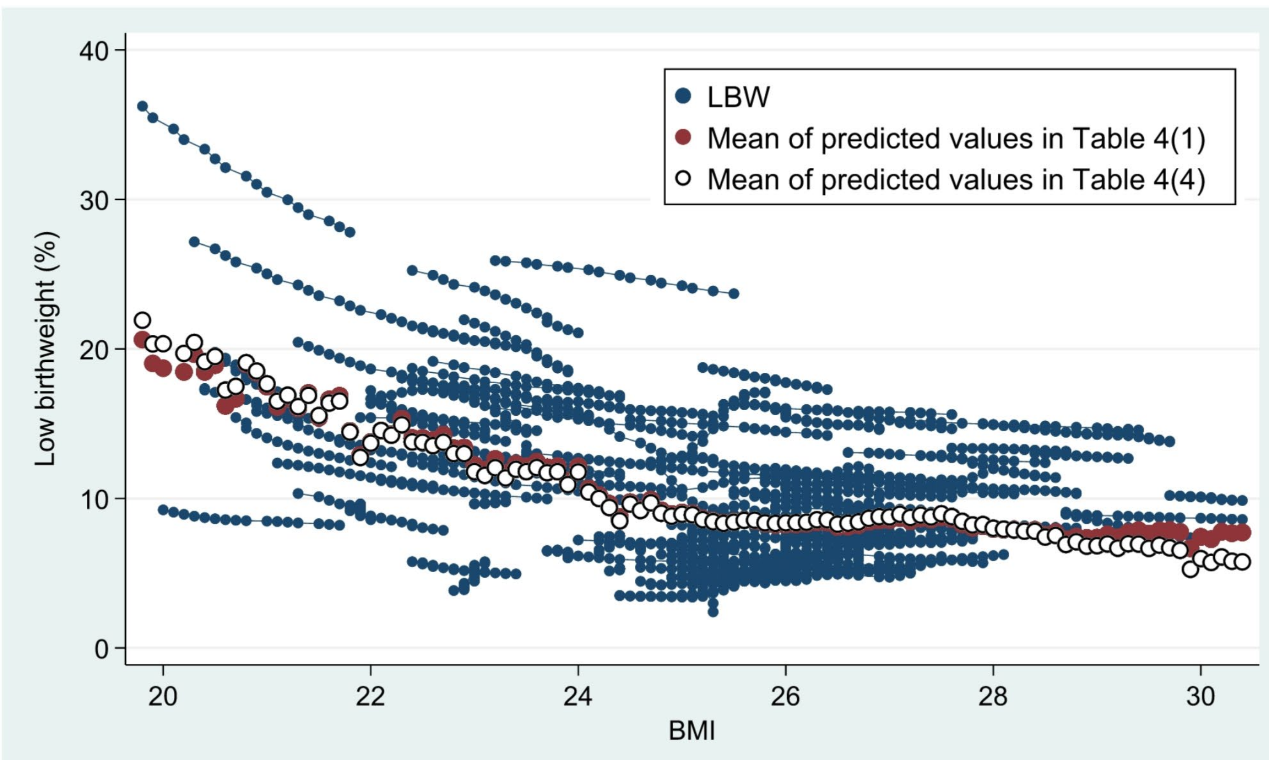

Fig. 2 Scatter plots of *BMI* and *R_LBW* with fitted values of quadratic and cubic functions. Scatter plots of *BMI* and *R_LBW* in each country 2000–2015 and fitted values of the quadratic and cubic functions presented in Eq. (1) are shown. The red dots represent the means at each *BMI* of predicted values calculated using the estimates by the quadratic function shown in column (1) of Table 4, and the white dots represent those estimated by the cubic function shown in column (4). The blue dots represent the observed values of *R_LBW*

negative, respectively, indicating that the impact of the financial crisis via *EMPLOYEE* significantly increased the low-birthweight rate but diminishingly.

Discussion

We posited four hypotheses on the relationship between the rate of low birthweight and the supposed risk factors. Data analysis supported the relationship, indicating the significance of our risk factors. However, two problems remained concerning Hypotheses 1 and 2. First, the shape of the function in regions of large *BMI* was not sufficiently clear. Although the estimation of the quadratic function revealed a U-shaped curve, the bottom of the U-shaped curve was located near the right edge of the observed value, suggesting that the association was decreasing but diminishing in most of the domains. It is not yet clear how the increased *BMI* will affect the incidence of low birthweight if *BMI* is further increased in the future. Second, *GDP*, which was found to be an important risk factor, was insignificant when *BMI* was added, suggesting that *GDP* is associated with *R_LBW*

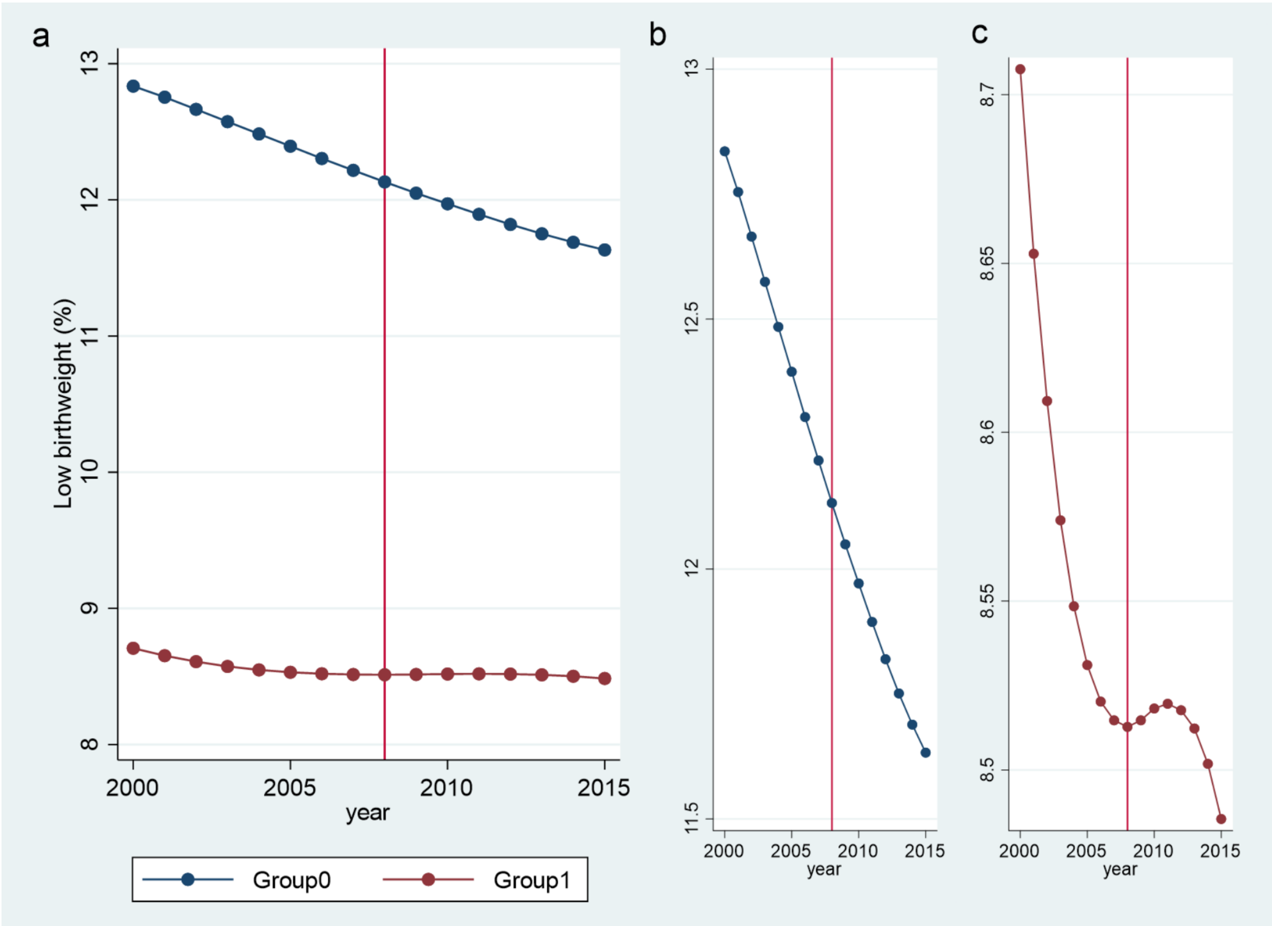

Fig. 3 Observed means of *R_LBW* for parallel trend. Panel **a**: Trend for both groups. Panel **b**: Trend for the control group. Panel **c**: Trend for the treatment group. Group1 (treatment) consists of the countries with real GDP growth rates in 2008 and 2009 in the bottom 50%, and Group 0 (control) represents all others

through many paths, including *BMI*. Examining this complex relationship remains a task for future studies.

This study found that the association of the rate of women's employment and that of low birthweight had an inverse U-shaped curve, with its peak being around 41%. This suggests that an increase in women's employment rate during the period of 2000–2015 was associated with a decline in the rate of low birthweight in low- and middle-income countries and improved the rate of low birthweight in high-income countries on average. *WEAK_LABOR* was not significant. Relation between *BIRTH_STAFF* and low-birthweight rate is a U-shaped curve, with its bottom being approximately 75%. Adolescent birth rate is significantly and positively associated with low-birthweight rate; specifically, a decrease in the adolescent birth rate decreases the low-birthweight rate.

The results can address how to achieve the goal of the 65th World Health Assembly to "reduce the incidence rate of low birth weight." Table 6 presents the contributions of each individual variable to the reduction in the rate of low-birthweight infants during the period of 2000–2015, which was calculated from the change in the magnitude and estimates of the coefficients shown in Column 1 of Table 4. Regarding the 1.3% decrease in fitted value of *R_LBW* in 16 years, although the increase in *BMI* contributed 54% of this reduction, the decrease in *YOUNG_MOTHER* contributed 30%, the increase in *GDP* contributed 13%, the increase in *BIRTH_STAFF* contributed 5%, and the increase in employment rate deteriorated rate of low birthweight slightly.[8]

Which is the most promising political instrument for the future? To answer this question, we must investigate the change in each variable by income-group countries. Over the 16 years examined, *R_LBW* improved from 16.1 to 10.2% in low-income countries, whereas it deteriorated slightly from 7.2 to 7.8% in high-income countries. These values suggest that low-income countries have room to reduce low birthweight rates. The variables in

[8] The estimated contributions in Table 6 should be interpreted with caution, as they are based on a limited set of variables. Other unmeasured factors may also influence changes in low-birthweight rates, and their effects are not captured in this analysis.

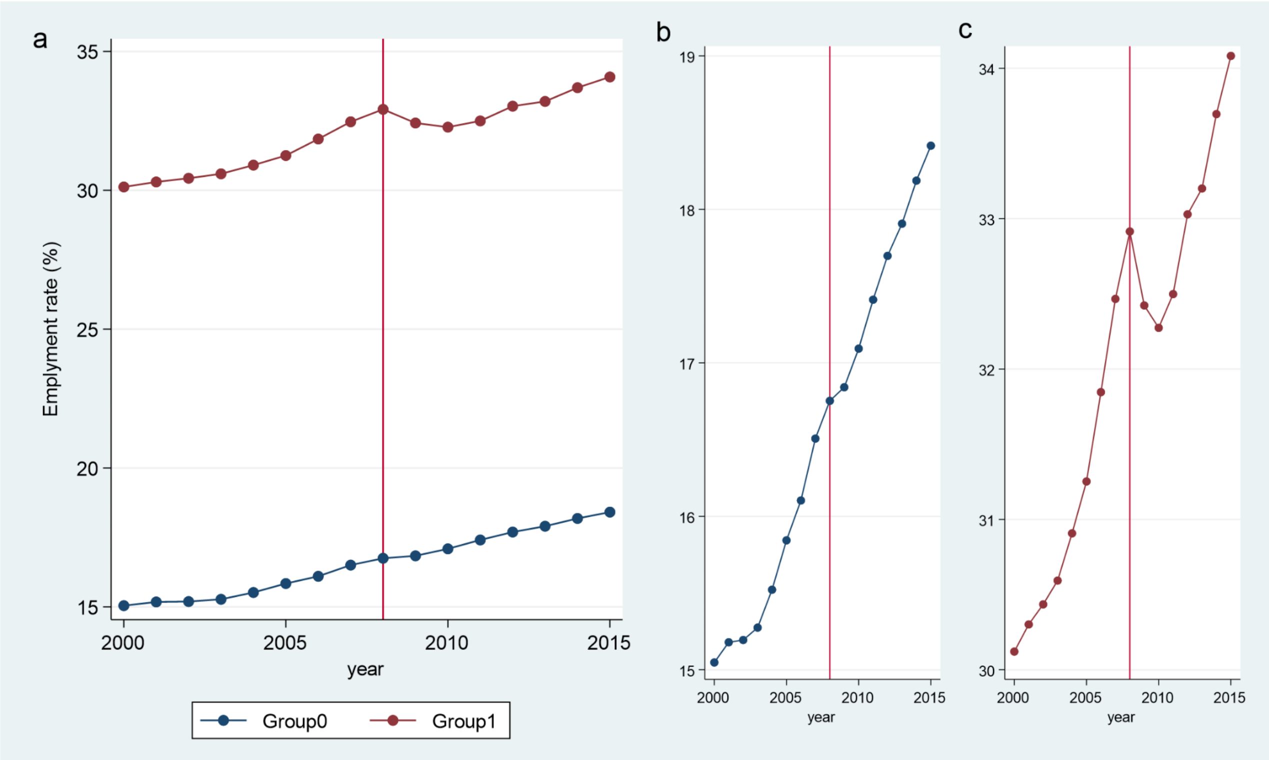

Fig. 4 Parallel trends in employment rates. Panel a: Employment rate trends for both groups. Panel b: Employment rate trend for the control group. Panel c: Employment rate trend for the treatment group. Observed employment rates for treatment and control groups before and after the 2008 financial crisis. Group1 (treatment) consists of the countries with real GDP growth rates in 2008 and 2009 in the bottom 50%, and Group 0 (control) represents all others

Table 6 may continue to be policy instruments, but their effectiveness will be weakened because the situations have already been improved even in the low-income countries over the 16 years examined: *BMI* 22.7 to 25.6, *BIRTH_STAFF* 50–86%, *YOUNG_MOTHER* from 9.5 to 7.6 births per 100 females. However, the *GDP* and employment rate of low-income countries were still substantially lower compared with high-income countries, that is, *GDP* US$ 4020 vs. US$ 41,728 and *EMPLOYEE* 17% vs. 46%. While improvements in standard of living and employment are expected to reduce low-birthweight rates, the most effective policy interventions will vary by country and require tailored approaches.

Although this study identifies key determinants of low birthweight, implementing effective policies requires adaptation to each country's unique economic, healthcare, and social conditions. For example, in low-income countries, improving maternal nutrition and access to healthcare may be the most effective strategy, whereas in high-income countries, addressing obesity-related pregnancy complications may be a greater priority.

Conclusions

This study identified the risk factors for low-birthweight births using data from 143 countries for 2000–2015. Although many risk factors have been identified using individual data in a country [4, 9, 12], international comparisons of low birthweight problems have not been adequately performed. A multi-county analysis is essential to determine whether these factors are systematically associated with low birthweight across diverse economic and healthcare systems. By comparing multiple countries, this study provides insights into both universal and country-specific determinants of low birthweight, helping to fill this gap in the literature.

In this study, we focused on five risk factors: women's BMI, per capita GDP, women's employment status, level of healthcare, and adolescent childbearing. We employed the quadratic and cubic functions in the estimation because the association between the rate of low-birthweight births and these variables is supposed to be non-linear. For policy applicability, this study used a fixed-effects model in which the estimates represent correlations between time-varying variations within a country. Furthermore, using the 2008 financial crisis as a natural experiment, the DID analysis provides evidence suggesting a relationship between GDP and low birthweight rate, where female employment rates play and important role. Thus, the results of this study represent a step toward policy use.

This study has several limitations. Among these, data availability may be the most significant. Variables such as

Table 5 The estimates of Eqs. (2) and (4): DID analysis

VARIABLES	**(1)**	**(2)**	**(3)**	**(4)**
CROSS	0.627***	0.575***	-0.453	-1.136***
	(0.138)	(0.139)	(0.407)	(0.407)
AFTER	-0.699***	-0.653***	-1.414***	-0.313*
	(0.116)	(0.126)	(0.217)	(0.176)
EMPLOYEE		-0.103**	-0.0476	0.108***
		(0.0417)	(0.0351)	(0.0387)
EMPLOYEE^2		0.00165***	0.000179	-0.00146***
		(0.000574)	(0.000689)	(0.000438)
CROSS_EMPLOYEE			0.0546**	0.0732***
			(0.0228)	(0.0224)
CROSS_EMPLOYEE^2			-0.00106***	-0.00101***
			(0.000284)	(0.000290)
AFTER_EMPLOYEE			0.0398***	0.0134**
			(0.00947)	(0.00659)
GROUP_EMPLOYEE			0.00276	-0.0036
			(0.0373)	(0.0217)
BMI				-48.80***
				(14.94)
BMI^2				1.851***
				(0.580)
BMI^3				-0.0235***
				(0.00748)
lnGDP				-0.0864
				(8.288)
lnGDP^2				-0.0572
				(0.926)
lnGDP^3				0.0043
				(0.0343)
WEAK_LABOR				0.0119
				(0.0228)
WEAK_LABOR^2				0.000157
				(0.000296)
BIRTH_STAFF				-0.0305
				(0.0184)
BIRTH_STAFF^2				0.000214
				(0.00014)
YOUNG_MOTHER				0.0988
				(0.065)
Constant	10.43***	11.66***	11.50***	439.7***
	(0.031)	(0.634)	(0.672)	(119.700)
Observations	2,145	2,100	2,100	1,304
R-squared	0.196	0.227	0.352	0.541
Number of countries	143	140	140	133

Dependent variable is *R_LBW*. The estimation method used was a fixed effects model. *GROUP* was omitted because of collinearity, as it was a constant variable throughout time. *CROSS* is *GROUP* multiplied by *AFTER*. Robust standard errors are indicated in the parentheses. In all the columns, $\boldsymbol{LABOR\_SQ_{i,t}} \times \boldsymbol{GROUP_{i,t}}$ **and** $\boldsymbol{AFTER_{i,t}} \times \boldsymbol{LABOR_{SQ_{i,t}}}$ were not included to obtain significant results. All analyses were conducted using *Stata*, and standard errors were clustered at the country level to account for within-country correlation over time. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6 Contributions of individual variables to the reduction in the rate of low-birthweight babies during the period of 2000–2015

	Mean		Contribution	
Variable	2000	2015	Δ*R_LBW_HAT*	%
BMI	24.9	26.1	-0.7	54.2
lnGDP	8.8	9.3	-0.2	13.3
EMPLOYEE	22.5	25.9	0.0	-2.6
BIRTH_STAFF	77.3	93.3	-0.1	4.9
YOUNG_MOTHER	6.4	5.0	-0.4	30.1
R_LBW_HAT (Total)	10.3	9.0	-1.3	100

R_LBW_HAT is the fitted value of *R_LBW* using the estimates in Column (1) of Table 4. Δ *R_LBW_HAT* was calculated from the change in the magnitude of the variables and the estimates of the coefficients between 2000 and 2015

the rate of high-birthweight infants, distribution of BMI, and rate of births by mothers aged over 40 years were not available. Obtaining more detailed data and using a more flexible functional form will be tasks for future studies. DID analysis should to be performed more carefully, considering the influence of unmeasured confounders.

Abbreviations

BMI	Body mass index
DID	Difference-in-differences
GDP	Gross domestic product
OECD	Organization for Economic Co-operation and Development
PWT	Penn World Table
UNICEF	United Nations Children's Fund
US	United States
WB	World Bank Open Data
WHO	World Health Organization

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12884-025-07477-4.

Supplementary Material 1: A: Country list. B: Actual vs. predicted low birthweight rates.

Acknowledgements

We would like to thank Professor Mitsuo Fukuda, Professor Yuichi Abiko, Professor Masafumi Kozuka, Associate Professor Shohei Ishibashi, Associate Professor Youki Kohsaka, and Assistant Professor Hidekazu Niwa for their guidance and comments. We would also like to express our appreciation for the financial support provided by the Japan Society for the Promotion of Science (JSPS KAKENHI, Grant Number 21K01534).

Author contributions

CY conducted literature searches, reviewed articles, analyzed the data, and drafted the manuscript. YT conceptualized and designed the study, synthesized the findings, and prepared the manuscript. Both CY and YT read and approved the final manuscript.

Funding

This study was supported by JSPS KAKENHI (Grant Number 21K01534).

Data availability

We gathered data for all countries for the period ranging from 2000 to 2015 from the World Bank data base (https://databank.worldbank.org/source/world-development-indicators), the UNICEF Data Warehouse (https://data.unicef.org/resources/data_explorer/unicef_f/), and the Penn World Table (https://www.rug.nl/ggdc/productivity/pwt/?lang=en).

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Clinical trial number

Not applicable.

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Received: 29 October 2023 / Accepted: 15 March 2025
Published online: 02 April 2025

References

1. Barker DJP, Osmond C, INFANT, MORTALITY. CHILDHOOD NUTRITION, AND ISCHAEMIC HEART DISEASE IN ENGLAND AND WALES. Lancet. 1986;327.
2. Barker DJP. The fetal and infant origins of adult disease. BMJ. 1990;301.
3. Currie J, Hyson R. Is the impact of health shocks cushioned by socioeconomic status?? The case of low birthweight. Am Econ Rev. 1999;89:245–50.
4. Currie J. Healthy, wealthy, and wise: socioeconomic status, poor health in childhood, and human capital development. J Econ Lit. 2009;47:87–122.
5. Doherty T, Kinney M. Low birthweight: will new estimates accelerate progress? Lancet Global Health. 2019;7:e809–10.
6. Mccance DR, Pettitt DJ, Hanson RL, Jacobsson LTH, Knowler WC, Bennett PH. Birth weight and non-insulin dependent diabetes: thrifty genotype, thrifty phenotype, or surviving small baby genotype? BMJ. 1994;308.
7. Rich-Edwards JW, Colditz GA, Stampfer MJ, Willett WC, Gillman MW, Hennekens CH, et al. Birthweight and the risk for type 2 diabetes mellitus in adult women. Ann Intern Med. 1999;130(4):I.
8. Yamane C, Tsutsui Y. Dose birthweight matter to quality of life? A comparison between Japan, the U.S., and India. Health Econ Rev. 2022;12:48.
9. Kramer MS. Determinants of low birth weight: methodological assessment and meta-analysis. Bull World Health Organ. 1987;65.
10. Brandt LPA, Nielsen C. v. Job stress and adverse outcome of pregnancy: A causal link or recall bias? Am J Epidemiol. 1992;135.
11. Mutambudzi M, Meyer JD, Warren N, Reisine S. Effects of psychosocial characteristics of work on pregnancy outcomes: A critical review. Women Health. 2011;51.
12. Keily JL, Brett KM, Yu S, Rowley DL. Low birth weight and intrauterine growth retardation. Birth Outcomes. 1994;:185–202.
13. Blencowe H, Krasevec J, de Onis M, Black RE, An X, Stevens GA, et al. National, regional, and worldwide estimates of low birthweight in 2015, with trends from 2000: a systematic analysis. Lancet Glob Health. 2019;7:e849–60.
14. Amabebe E, Ikumi N, Pillay K, Matjila M, Anumba D. Maternal obesity-related placental dysfunction: from peri-conception to late gestation. Placenta Reproductive Med. 2023;2.
15. Matysiak A, Sobotka T, Vignoli D. The great recession and fertility in Europe: A Sub-national analysis. Eur J Popul. 2021;37.
16. Hessel P, Vandoros S, Avendano M. The differential impact of the financial crisis on health in Ireland and Greece: A quasi-experimental approach. Public Health. 2014;128.
17. Physical status: the use and interpretation of anthropometry. Report of a WHO expert committee. World Health Organ Tech Rep Ser. 1995;854.
18. He Z, Bishwajit G, Yaya S, Cheng Z, Zou D, Zhou Y. Prevalence of low birth weight and its association with maternal body weight status in selected countries in Africa: A cross-sectional study. BMJ Open. 2018;8.
19. Kruk ME, Gage AD, Arsenault C, Jordan K, Leslie HH, Roder-DeWan S et al. High-quality health systems in the sustainable development goals era: time for a revolution. Lancet Global Health. 2018;6.

20. Bidstrup SB, Kaerlev L, Thulstrup AM, Ellekilde Bonde JP. Women referred for occupational risk assessment in pregnancy have no increased risk of adverse obstetric outcomes. Dan Med J. 2015;62.
21. Jahromi BN, Husseini Z. Pregnancy outcome at maternal age 40 and older. Taiwan J Obstet Gynecol. 2008;47.
22. Blomberg M, Tyrberg RB, Kjølhede P. Impact of maternal age on obstetric and neonatal outcome with emphasis on primiparous adolescents and older women: A Swedish medical birth register study. BMJ Open. 2014;4.
23. Kyozuka H, Fujimori K, Hosoya M, Yasumura S, Yokoyama T, Sato A et al. The effect of maternal age at the first childbirth on gestational age and birth weight: the Japan environment and children's study (JECS). J Epidemiol. 2019;29.
24. Angrist JD, Pischke J. Mostly harmless econometrics: an empiricist's companion. Princeton University Press; 2009.
25. Nolan A, Barry S, Burke S, Thomas S, Al, Et. The impact of the financial crisis on the health system and health in Greece. European Observatory on Health Systems and Policies; 2014.
26. Vandoros S, Hessel P, Leone T, Avendano M. Have health trends worsened in Greece as a result of the financial crisis? A quasi-experimental approach. Eur J Public Health. 2013;23.
27. UNFPA. Unfinished Business: the pursuit of rights and choices FOR ALL. State of the World Population 2019. 2019.
28. Gokmen G, Morin A. Inequality in the aftermath of financial crises: some empirical evidence. Appl Econ Lett. 2019;26.

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