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The Contribution of Maternal Birth Cohort to Term Small for Gestational Age in the U.S. 1989–2010: an Age, Period, and Cohort Analysis

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Abstract

Background—After decades of steady increase, mean birthweight in the U.S. declined throughout the 1990s and early 2000s, a trend not fully explained by changes in length of gestation, medical practice, demographics, or maternal behaviors. We hypothesized that secular changes in health or social factors across women’s lifecourses may have contributed to this unexplained trend and examined maternal birth cohort as a proxy measure of lifecourse determinants of fetal growth in the U.S.

Methods—We used the age, period, and cohort (APC) intrinsic estimator (IE) approach to estimate the contribution of maternal birth cohort (independent of maternal age and period of birth) to small for gestational age (SGA), overall and among term births, in the U.S. from 1989–2010. We conducted analyses separately among foreign- and U.S.-born Hispanic, non-Hispanic black (NHB), and non-Hispanic white (NHW) mothers.

Results—We found evidence of a U-shaped relationship between maternal birth cohort and SGA among NHB women only. After accounting for maternal age and period of birth, risk of SGA among NHB women born in 1950 was 21.1% and decreased to 15.9% in 1970. However, NHB women born after 1970 experienced increasing risk (19.6% by the 1986 birth cohort).

Conclusions—Our findings suggest that NHB women born after 1970 have experienced increasing risk of SGA. Declining risk of SGA across NHB maternal birth cohorts from 1950–1970, however, suggests the potential to reverse this trend. Results illustrate the need for research on health and social risk factors for SGA across the pre-pregnancy lifecourse.

Birthweight is highly correlated with neonatal and infant morbidity and mortality as well as later-life chronic disease, mental health, and socioeconomic status (SES) and is therefore often considered a measure of both current and future population-level health. Mean birthweights in the U.S. climbed steadily throughout much of the twentieth century.^{1, 2} In the late 1990s, however, mean birthweight began to decrease and rates of low birthweight (LBW) began to increase.³ Because infant birthweight reflects both adequacy of fetal growth and length of gestation, much of this secular decline was at first attributed to a shift in the distribution of gestational age due to increased use of procedures such as induction of labor

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and cesarean delivery.³ Declining birthweights were also attributed to demographic shifts, such as increasing proportions of multiple births and births to older mothers³. However, a recent study showed that mean birthweight declined substantially between 1990 and 2005 at every week of term gestation (weeks 37–41).⁴ Moreover, the overall decline in birthweight was almost 80g over the 15-year period among a subgroup of singleton births to low-risk women (25–29 years of age, non-Hispanic white, 13 years of education, married, prenatal care in the first trimester, non-smoking, no pregnancy complications, vaginal delivery, no labor induction, prenatal ultrasound, and pregnancy weight gain of 26–35 pounds).⁴ These findings—which demonstrate a secular decline in birthweight in the U.S. that cannot not be explained by changes in length of gestation or traditional demographic, socioeconomic, medical care or behavioral risk factors—indicate a need for research into other, unexplored population-level determinants of fetal growth.

In this vein, growing evidence suggests that maternal health and social factors prior to pregnancy, particularly during the *in utero* and early childhood periods, may influence later-life risk of adverse birth outcomes. Examples of such factors include childhood nutrition and growth,^{5–7} exposure to financial and social hardships,⁸ and being born in a poor neighborhood.⁹ Unfortunately, population-level data on maternal exposures early in life linked with later-life birth outcomes are scarce, especially in the U.S. Birth cohorts, however, can serve as proxy measures of both individual and contextual socioeconomic, behavioral, and environmental exposures over the life course.¹⁰ Cohort effects are often contrasted with age effects (which measure factors that change as individuals age) and period effects (which measure factors that change over chronological time).

The objective of this study was to examine the contribution of maternal birth cohort (independent of maternal age and period of birth) to fetal growth over the last two decades in the U.S. Our central hypothesis is that mothers' health and social exposures prior to pregnancy contribute to fetal growth of their own infants and that secular changes in these exposures may contribute to population-level trends in fetal growth. To test this hypothesis, we examined age, period, and cohort (APC) models of small for gestational age (SGA) overall and among term births only in the U.S. from 1989–2010. In light of stark racial/ethnic disparities in fetal growth¹¹ and substantial racial/ethnic differences in cohort experiences in the US, we also hypothesized that maternal birth cohort associations with term SGA would differ by race/ethnicity. We therefore stratified our analysis by race/ethnicity and nativity, focusing on the four largest groups in the U.S.: foreign- and U.S.-born Hispanics, non-Hispanic blacks, and non-Hispanic whites.

Methods

Data

Data were obtained from the National Center for Health Statistics (NCHS) natality files from 1989–2010 (n=89,426,378). Because the birth certificate format changed in 2003, and uptake of the new certificate has varied by state (with only 33 states using the new format as of 2010), we used variables collected consistently across the two formats, including gestational age based on last menstrual period (LMP), birthweight, maternal age, race, and Hispanic origin. We obtained permission from NCHS to access restricted data on nativity

status for 2004–2010. We limited our analyses to singleton births to US residents (n=86,640,053) of Hispanic, non-Hispanic black, or non-Hispanic white race/ethnicity with available data on nativity status (n=80,600,685) and birthweight (n=80,529,193).

In our primary analyses, we also excluded births missing length of gestation calculated from date of LMP (n = 3,863,762). (Although natality files also report length of gestation based on clinical/obstetric estimates, the procedures used to obtain this estimate differ between the 1989 and 2003 birth certificates,¹² making these data less appropriate for analyses of trends. We compared results including and excluding clinical estimates and found that they were substantively similar.) We also excluded births with <22 or >44 weeks gestation (n = 1,439,356) due to questionable reliability of data, resulting in a sample size of 75,226,075. We also created a subsample of term births (>37 weeks gestation, n = 67,552,524).

Variables

Because birthweight alone conflates fetal growth and gestational age, we used small for gestational age (SGA) as our primary measure of fetal growth. SGA births are defined as being <10th percentile of weight for gestational age based on a national distribution from 1999–2000.¹³ SGA compares infants to a national distribution of live births, which means that preterm infants are compared to a more select population (only those born early) than term infants; this selection issue has been shown to induce bias in studies of the etiology of fetal growth.¹⁴ We therefore focused our main analyses on SGA among only term births (called “term SGA” for brevity) but conducted a secondary analysis of SGA among all births. Use of term SGA as our primary outcome also makes these findings most comparable to previous work.¹⁵ Additionally, because of the many concerns about quality of data on length of gestation measured from LMP,^{16,17} we also examined term LBW (<2500 g at >37 weeks gestation). Finally, we assessed preterm birth (PTB, <37 weeks completed gestation) as a comparison measure.

We categorized race/ethnicity as Hispanic, non-Hispanic white or non-Hispanic black using birth certificate data on race and Hispanic ethnicity. We stratified Hispanic mothers by nativity status (i.e., foreign- and US-born) because we hypothesized that cohort influences on women born outside the U.S. might differ from U.S.-born women and because foreign-born women make up approximately 60% of Hispanic mothers. We categorized maternal age as follows: <15, 15–19, 20–24, 25–29, 30–34, 35–39, 40–44, and >44 years. Because of the large sample size, we estimated separate period effects for each year of birth from 1989–2010. With $I = 8$ age groups and $J = 22$ periods, the number of cohorts in the resulting APC model is necessarily $I + J - 1$, for a total of 29 two-year cohorts (i.e., 1940–41, 1942–43, etc.)

Statistical analysis

We first calculated the crude (unadjusted) rates of SGA among singleton, term live births by age, cohort, and period by race/ethnicity/nativity. We then used logit models to estimate APC models of term SGA using tabular data formed by a cross-classification of maternal age and period. These logit models take the form of:

$$\text{logit}(p_{ij}) = \beta_0 + \beta_i^A + \beta_j^P + \beta_k^C,$$

where β_0 is a constant; β_i^A represents the age effect for $i=1, \dots, I$ age groups; β_j^P represents the period effect for $j=1, \dots, J$ periods; and β_k^C represents the cohort effect for $k=1, \dots, I+J-1$ cohorts, where the index $k = I - i + j$. These effects are parameterized to sum to 0 over each APC factor. That is, $\sum_i \beta_i^A = \sum_j \beta_j^P = \sum_k \beta_k^C = 0$, and therefore β_0 is interpreted as a grand mean. As has been discussed in detail elsewhere, maternal birth cohort is linearly dependent on period and age (i.e., cohort = period – age), making the model non-identifiable using standard estimation techniques unless a constraint is imposed on one of the APC parameters.^{18,19} One approach to the identification problem is provided by the intrinsic estimator (IE), which uses principal components regression to obtain estimates of all APC effects.^{20,21} The IE approach is one of several approaches to solving the APC identification problem and relies on the constraints implied by the IE.¹⁹ It is recommended that results be cross-validated using alternative estimation techniques.²² Our IE results were nearly indistinguishable from those obtained using hierarchical APC random effects (HAPCRE) models (Appendix A), so we present results from the IE models here.

We stratified models by race/ethnicity and nativity. We then used coefficients from the APC model results to calculate the probability of term SGA for each maternal birth cohort, age category, and period of birth, by race/ethnicity/nativity. Due to the large sample size (which can make small differences statistically significant), we focus on examining the magnitude and practical significance of our findings. Although our analyses focus on maternal birth cohort, we also report the independent contributions of maternal age and period of birth to fetal growth by race/ethnicity/nativity. We used the same methods for overall SGA and term LBW. Data management was performed with SAS software (SAS Institute, Cary NC) and analyses were conducted using the `ie_rate`²³ procedure in Stata software (StataCorp LP, College Station TX).

Results

Descriptive analyses

Table 1(a–d) shows the crude proportion of SGA among singleton, term live births, by maternal birth cohort and age among each of the four race/ethnicity/nativity groups.

Age, period, and cohort analyses

Table 2 shows the age-, period-, and cohort-specific probabilities with confidence intervals (based on the APC models) of term SGA by race/ethnicity/nativity. (Coefficients from APC models are shown with confidence intervals in Appendix B.) The maternal birth cohort-specific probabilities (independent of maternal age or period of birth) for term SGA are graphically displayed in Figure 1. Among NHB women, there is evidence of a U-shaped relationship between maternal birth cohort and term SGA. The probability of term SGA among NHB mothers was highest for those born in 1946–47 with a probability of 0.225 (95% confidence interval [CI]: 0.213, 0.237). The probability of term SGA then declined

steadily among maternal cohorts born from the late 1950s until 1968–69, reaching a nadir of 0.158 (95% CI: 0.153, 0.163) in 1968–69. Probabilities began to rise again for NHB mothers born after 1970, reaching 0.196 (95% CI: 0.191, 0.201) for the 1986 birth cohort, and continued to climb steadily until the early 1990s. The data may suggest a similar but much weaker pattern among NHW and U.S.-born Hispanic mothers, but there is little evidence of a cohort pattern among foreign-born Hispanic mothers.

Figures 2 and 3 show the age- and period-specific probabilities of term SGA (based on coefficients from the APC models) by race/ethnicity/nativity. With regard to age, probability of term SGA was highest among mothers <20 years old and declined steadily for mothers from ages 20 to 30–34. Risk of SGA increased again after age 34 but never reached the level seen among the youngest mothers. With regard to period, there was evidence of a slight increase in probability of term SGA from 1989 through the late 1990s and a slight decrease in SGA throughout the 2000s. Regardless of age, period, or cohort, risk of term SGA was consistently highest among NHB women and lowest among NHW women, with foreign-born Hispanic women having slightly lower risks than their US-born counterparts. Only the maternal birth cohort pattern differed substantially by race/ethnicity.

Our analysis of SGA among all (both term and preterm) births and our analysis of term LBW found similar age, period, and cohort estimates for all groups (Appendix C and D). APC models for PTB revealed a similar U-shaped association between maternal age and probability of PTB but showed little evidence of strong period or cohort effects (Appendix E).

Prompted by the unexpected nature of our finding of increasing risk of SGA for NHB mothers born after 1970, we conducted two additional analyses. First, we constructed plots of the crude (unadjusted) percent of term SGA among NHB women by age and period, age and cohort, and period and cohort. These plots (Appendix F) confirm our finding of a relatively stable period effect, a strong U-shaped relationship between age and term SGA, and a U-shaped relationship between cohort and term SGA. Specifically, these graphs show 1) increasing risk of term SGA among NHB women born after 1970, regardless of period of birth, and 2) U-shaped relationships between maternal birth cohort and term SGA among the lowest risk age groups (20–24, 25–29, and 30–34). Second, we conducted another analysis stratifying NHB women by nativity; results are displayed in Figure 4. We found evidence of the U-shaped relationship between maternal birth cohort and risk of SGA only among U.S.-born NHB mothers ($n = 8,907,939$). Although the estimates for foreign-born NHB mothers exhibited more variation (due to the smaller sample size; $n = 1,065,383$), the overall pattern showed declining risk of SGA with successive maternal birth cohorts (Figure 4).

Conclusions

We examined the contribution of maternal birth cohort—independent of maternal age and period of birth—to risk of term SGA among the four largest race/ethnicity/nativity groups in the U.S. using natality data from 1989–2010. Our findings suggest a U-shaped relationship between maternal year of birth and term SGA among NHB women. In this group, risk of SGA was highest among women born in the late 1940s and declined steadily for cohorts in

the 1950s and 1960s (with a 25% decline from 1950 to 1970). However, risk of SGA then increased again for cohorts born after 1970, such that NHB mothers born in 1990 had the same risk of term SGA as mothers born in 1950. Among NHB women, the relationship between maternal birth cohort and SGA was stronger than the relationship between year of birth and SGA, suggesting that health and/or social exposures prior to pregnancy may play an important role in determining the fetal growth of women's own infants.

As far as we know, this is the first study to identify this U-shaped maternal birth cohort pattern in fetal growth among non-Hispanic black women in the U.S. These findings do, however, build on the earlier work of Ananth and colleagues¹⁵ examining APC effects on term SGA among black and white births between 1975 and 2000. These authors reported increasing risk of term SGA among black women born between 1941 and 1960, followed by a decline in risk of term SGA among black women born in the 1960s, a finding similar to that from our study. A recent study of age, period, and cohort effects on the infant mortality rate (IMR) also reported declines in the NHB IMR among mothers born around the time of the Civil Rights movement.²⁴

While it is beyond the scope of this study to determine the cause of these cohort associations, we can hypothesize that the declines in risk of term SGA seen among NHB women born in the late 1950s through 1970 may be due to the social, economic, political, and health-related gains achieved by the Civil Rights movement.²⁴ The concerning reversal of this trend beginning around 1970 is, however, more difficult to explain. Potential explanations for the increase in risk of SGA among NHB women born after 1970 should focus on health or social factors prior to pregnancy that 1) have a plausible effect on a woman's birth outcomes, 2) have increased from the 1970 until at least the early 1990s, and 3) differ by race/ethnicity in a way that could plausibly impact NHB women more than other groups. One potential explanation lies in the dramatic increase in obesity in the U.S. starting in the 1970s, which disproportionately affected NHB women.²⁵ NHB women born during this time period were more likely than their predecessors to have been exposed to obesogenic maternal environments *in utero* and to have been overweight themselves throughout pre-pregnancy life. It remains unknown, however, exactly how *in utero* or pre-pregnancy exposure to obesity might influence later-life birth outcomes.

Another potential explanation lies in social and economic changes such as declining manufacturing jobs, growing inner city poverty, and increasing proportions of single-parent families, all of which are thought to have contributed to increasing poverty and disadvantage in the black community over this time period.^{26,27} Indeed, other work has shown links between early life adversity at both the individual and neighborhood level and increased risk of adverse birth outcomes later in life.^{8,9} The fact that the U-shaped relationship between maternal birth cohort and risk of SGA was observed only among U.S.-born NHB women provides further evidence that this pattern reflects unique characteristics of the experience of NHB women in the U.S. that are not shared by women of other racial/ethnic groups or NHB women who spend the early part of their lives outside of the U.S.

Prior literature suggests several mechanisms by which health, socioeconomic status, or other exposures prior to pregnancy could influence pregnancy outcomes. Hypothesized

mechanisms include fetal or early life programming of later life health,^{28,29} which may occur via epigenetic mechanisms;^{30,31} disruption of physiological systems (e.g., endocrine, cardiovascular, or metabolic) due to chronic stress or hardship across the lifecourse (i.e., allostatic load or weathering hypotheses);^{8,28,32,33} and impacts of the environment at critical periods on behaviors such as smoking.²⁸

We also found evidence of a U-shaped relationship between maternal age and risk of SGA, as has been reported in many previous studies. Prior research has reported that age-related increases in risk of LBW are steeper among black compared to white women, a finding that has been attributed to more-rapidly deteriorating health status among black women at younger ages (i.e., weathering).³² Our findings, however, did not indicate substantial differences in the relation between age and risk of term SGA by race/ethnicity. After accounting for maternal birth cohort and age, our results showed only a modest period effect on term SGA, with increasing risk from 1989 to the late 1990s and decreasing risk throughout the 2000s.

Several important limitations of the current study should be noted. First, we focus only on maternal birth cohort, maternal age, and period of birth as determinants of birth outcomes, yet we know that many other factors, including maternal smoking, pre-pregnancy body size, weight gain, marital status, and education also influence risk of adverse birth outcomes. Alternative APC methods, such as the HAPCRE, could allow for analysis of the effects of covariates as well as assessing possible mediators of cohort effects using individual-level data. Although these individual-level analyses are beyond the scope of this study, they remain an important area for future work. Second, alternative specifications such as HAPCRE could allow for the inclusion of cross-level interactions (e.g., age $\times$ period or age $\times$ cohort); however, the descriptive data presented here (Table 1 and Appendix F) do not suggest strong evidence of such interactions. Third, length of gestation was estimated using date of LMP, which is notoriously inaccurate, and measurement error may vary across age, period, and cohort. Notably, however, our findings were similar when we included clinical/obstetric measures. Moreover, we found no evidence for a cohort effect on PTB, suggesting that the observed cohort pattern in term SGA is not an artifact of changes in measurement of gestational age, which would also affect rates of PTB.

Third, approximately 7% ($n=5,374,610$) of the source population of single births to US residents of Hispanic, non-Hispanic black, or non-Hispanic white race/ethnicity ($n=80,600,685$) was excluded due to missing or implausible values for birth weight or gestational age. The percent of observations excluded did not vary substantially across years; however, prior work has shown that missingness and implausibility of gestational age data may differ by race/ethnicity and maternal age.^{34,35} In order for the observed cohort association to be accounted for by missing data, however, a higher proportion of non-Hispanic black infants born term SGA would have to be missing between 1950 and 1970, compared to prior to 1950 and after 1970, which does not seem likely. Finally, although the IE estimator is just one of several approaches to solving the APC identification problem, with the tabular data used here the results are very similar regardless of the optimization strategy.³⁶

In conclusion, we found that, among US-born NHB women, risk of term SGA declined for mothers born throughout the late 1950s and 1960s but *increased* for mothers born after 1970. This is a concerning finding, especially in light of evidence suggesting links between fetal growth and later life health and the already stark racial/ethnic disparities between black and white birth outcomes in the US. Importantly, the fact that risk of term SGA was *lower* among earlier cohorts of NHB mothers suggests the potential to reverse this trend again. These findings reinforce the importance of continued efforts to understand the individual and contextual determinants of maternal pregnancy health that accumulate across the life course and across generations.^{28,30}

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Appendix A. Coefficients and 95% confidence intervals for age, period, and cohort (APC) groups from APC logit models of small for gestational age (SGA) among singleton, term live births in the U.S. from 1989–2010 (n=67,552,524), stratified by race/ethnicity/nativity

	Coefficients from APC models for term SGA			
	Foreign-born Hispanic	US-born Hispanic	Non-Hispanic Black	Non-Hispanic White
Maternal age				
<15	0.57 [0.53, 0.61]	0.39 [0.35, 0.43]	0.33 [0.31, 0.35]	0.45 [0.42, 0.50]
15–19	0.32 [0.31, 0.34]	0.26 [0.24, 0.30]	0.21 [0.20, 0.22]	0.39 [0.38, 0.39]
20–24	0.05 [0.04, 0.06]	0.09 [−0.00, 0.040]	0.01 [0.01, 0.02]	0.12 [0.11, 0.12]
24–29	−0.20 [−0.21, −0.19]	−0.18 [−0.20, −0.17]	−0.15 [−0.16, −0.15]	−0.20 [−0.21, −0.20]
30–34	−0.32 [−0.33, −0.30]	−0.27 [−0.29, −0.25]	−0.22 [−0.23, −0.21]	−0.34 [−0.35, −0.34]
35–39	−0.31 [−0.33, −0.30]	−0.23 [−0.26, −0.21]	−0.18 [−0.19, −0.17]	−0.30 [−0.31, −0.29]
40–44	−0.18 [−0.20, −0.16]	−0.06 [−0.09, −0.03]	−0.06 [−0.08, −0.04]	−0.16 [−0.17, −0.15]
>44	0.07 [0.00, 0.13]	0.08 [−0.04, 0.20]	0.06 [0.01, 0.12]	0.05 [0.02, 0.08]
Period of birth				
1989	0.03 [0.00, 0.7]	−0.02 [−0.08, 0.04]	−0.13 [−0.16, −0.10]	−0.05 [−0.06, −0.03]
1990	0.02 [−0.01, 0.05]	−0.03 [−0.09, 0.02]	−0.11 [−0.14, −0.08]	−0.04 [−0.05, −0.03]
1991	0.03 [0.00, 0.06]	−0.00 [−0.05, 0.05]	−0.04 [−0.07, −0.02]	−0.01 [−0.02, 0.01]
1992	0.02 [−0.00, 0.05]	0.02 [−0.03, 0.06]	−0.02 [−0.04, 0.01]	0.00 [−0.09, 0.01]
1993	0.03 [0.00, 0.05]	0.04 [−0.00, 0.08]	0.02 [0.01, 0.04]	0.03 [0.02, 0.04]
1994	0.03 [0.01, 0.05]	0.04 [0.01, 0.08]	0.07 [0.06, 0.09]	0.05 [0.04, 0.06]
1995	0.03 [0.01, 0.04]	0.05 [0.02, 0.08]	0.10 [0.08, 0.11]	0.07 [0.07, 0.08]
1996	0.03 [0.01, 0.05]	0.06 [0.03, 0.09]	0.12 [0.11, 0.14]	0.09 [0.08, 0.10]
1997	0.00 [−0.01, 0.02]	0.04 [0.02, 0.06]	0.10 [0.09, 0.12]	0.07 [0.06, 0.08]
1998	−0.03 [−0.05, −0.02]	0.01 [−0.01, 0.03]	0.010 [0.09, 0.12]	0.04 [0.04, 0.05]
1999	−0.06 [−0.08, −0.05]	−0.02 [−0.04, −0.00]	0.08 [0.07, 0.09]	0.02 [0.02, 0.03]
2000	−0.05 [−0.07, −0.04]	−0.00 [−0.02, 0.02]	0.07 [0.06, 0.08]	0.01 [0.01, 0.02]
2001	−0.06 [−0.08, −0.05]	−0.01 [−0.03, 0.01]	0.05 [0.04, 0.07]	0.01 [0.00, 0.01]
2002	−0.05 [−0.06, −0.04]	−0.01 [−0.03, 0.02]	0.04 [0.03, 0.06]	−0.01 [−0.01, 0.00]
2003	−0.04 [−0.05, −0.02]	0.01 [−0.02, 0.03]	0.03 [0.09, 0.05]	−0.02 [−0.03, −0.01]
2004	−0.02 [−0.03, 0.00]	0.01 [−0.02, 0.04]	0.02 [0.01, 0.04]	−0.01 [−0.02, −0.01]
2005	−0.00 [−0.02, 0.02]	−0.01 [−0.02, 0.02]	−0.02 [−0.03, 0.00]	−0.03 [−0.04, −0.03]
2006	0.00 [−0.02, 0.02]	−0.01 [−0.05, 0.03]	−0.034 [−0.06, −0.02]	−0.04 [−0.05, −0.03]
2007	−0.01 [−0.03, 0.01]	−0.04 [−0.08, 0.00]	−0.08 [−0.10, −0.06]	−0.05 [−0.06, −0.04]
2008	0.02 [−0.00, 0.05]	−0.04 [−0.09, 0.01]	−0.08 [−0.11, −0.06]	−0.05 [−0.06, −0.04]

	Coefficients from APC models for term SGA			
	Foreign-born Hispanic	US-born Hispanic	Non-Hispanic Black	Non-Hispanic White
2009	0.03 [0.00, 0.06]	-0.05 [-0.10, 0.01]	-0.15 [-0.18, -0.12]	-0.06 [-0.07, -0.04]
2010	0.06 [0.03, 0.09]	-0.03 [-0.09, 0.03]	-0.16 [-0.19, -0.13]	-0.04 [-0.06, -0.03]
Maternal birth cohort				
1940	-0.09 [-0.53, 0.35]	-0.09 [-1.03, 0.85]	-0.07 [-0.514, 0.37]	0.22 [0.01, 0.43]
1942	0.01 [-0.10, 0.12]	0.04 [-0.15, 0.24]	0.05 [-0.044, 0.15]	0.06 [0.02, 0.11]
1944	0.05 [-0.02, 0.12]	0.08 [-0.04, 0.20]	0.14 [0.084, 0.20]	0.06 [0.03, 0.09]
1946	0.01 [-0.05, 0.06]	0.10 [-0.00, 0.20]	0.24 [0.190, 0.29]	0.09 [0.06, 0.11]
1948	0.01 [-0.04, 0.06]	0.11 [0.01, 0.20]	0.21 [0.166, 0.26]	0.06 [0.04, 0.09]
1950	0.00 [-0.04, 0.04]	0.06 [-0.03, 0.15]	0.16 [0.120, 0.20]	0.09 [-0.00, 0.04]
1952	-0.01 [-0.05, 0.03]	0.03 [-0.05, 0.12]	0.08 [0.042, 0.12]	-0.02 [-0.04, 0.01]
1954	-0.01 [-0.05, 0.03]	0.02 [-0.06, 0.10]	0.04 [-0.001, 0.07]	-0.04 [-0.06, -0.02]
1956	-0.03 [-0.06, 0.01]	-0.02 [-0.10, 0.05]	-0.03 [-0.060, 0.010]	-0.06 [-0.08, -0.05]
1958	-0.04 [-0.07, -0.00]	-0.05 [-0.12, 0.02]	-0.08 [-0.117, -0.05]	-0.08 [-0.10, -0.07]
1960	-0.03 [-0.06, 0.01]	-0.06 [-0.12, 0.00]	-0.14 [-0.168, -0.11]	-0.10 [-0.12, -0.09]
1962	-0.03 [-0.06, 0.00]	-0.06 [-0.12, -0.01]	-0.17 [-0.194, -0.14]	-0.12 [-0.13, -0.10]
1964	-0.00 [-0.03, 0.03]	-0.08 [-0.13, -0.03]	-0.19 [-0.213, -0.16]	-0.12 [-0.13, -0.10]
1966	-0.01 [-0.03, 0.02]	-0.09 [-0.14, -0.04]	-0.19 [-0.217, -0.17]	-0.11 [-0.13, -0.10]
1968	0.02 [-0.01, 0.05]	-0.09 [-0.13, -0.04]	-0.20 [-0.218, -0.18]	-0.11 [-0.13, -0.10]
1970	0.04 [0.02, 0.07]	-0.07 [-0.11, -0.04]	-0.19 [-0.209, -0.17]	-0.10 [-0.11, -0.09]
1972	0.04 [0.02, 0.06]	-0.06 [-0.09, -0.03]	-0.17 [-0.186, -0.15]	-0.08 [-0.09, -0.07]
1974	0.06 [0.04, 0.08]	-0.05 [-0.08, -0.02]	-0.14 [-0.154, -0.12]	-0.06 [-0.07, -0.05]
1976	0.04 [0.02, 0.06]	-0.03 [-0.06, -0.01]	-0.12 [-0.130, -0.10]	-0.04 [-0.05, -0.03]
1978	0.05 [0.03, 0.06]	-0.02 [-0.04, -0.00]	-0.09 [-0.102, -0.08]	-0.02 [-0.03, -0.01]
1980	0.04 [0.03, 0.06]	-0.00 [-0.02, 0.01]	-0.05 [-0.058, -0.04]	0.02 [0.01, 0.03]
1982	0.03 [0.02, 0.05]	0.00 [-0.01, 0.02]	-0.01 [-0.024, -0.00]	0.05 [0.04, 0.06]
1984	0.03 [0.02, 0.05]	0.04 [0.03, 0.06]	0.03 [0.022, 0.04]	0.06 [0.05, 0.07]
1986	0.03 [0.02, 0.05]	0.05 [0.03, 0.07]	0.07 [0.054, 0.08]	0.08 [0.07, 0.09]
1988	0.02 [-0.00, 0.03]	0.06 [0.04, 0.08]	0.12 [0.105, 0.13]	0.10 [0.09, 0.11]
1990	0.01 [-0.02, 0.03]	0.08 [0.05, 0.11]	0.16 [0.147, 0.18]	0.11 [0.10, 0.12]
1992	-0.03 [-0.06, -0.01]	0.07 [0.04, 0.11]	0.20 [0.184, 0.22]	0.10 [0.09, 0.12]
1994	-0.02 [-0.06, 0.01]	0.04 [0.00, 0.09]	0.22 [0.191, 0.24]	0.07 [0.05, 0.09]
1996	-0.18 [-0.45, 0.08]	-0.02 [-0.20, 0.16]	0.10 [-0.049, 0.25]	-0.05 [-0.26, 0.17]

Appendix B. Comparison of coefficients¹ obtained from age, period, and cohort (APC) models of small for gestational age using the hierarchical APC random effects (HAPCRE) approach (GLMM) and the intrinsic

estimator (IE) approach among singleton, term live births in the U.S. from 1989–2010 (n=67,552,524) by race/ethnicity/nativity

Appendix C. Probabilities of small for gestational age (SGA) by maternal age, period of birth, and maternal birth cohort (based on age-period-cohort models) among singleton live births in the U.S. from 1989–2010 (n=75,226,075)

Appendix D. Probabilities of low birth weight (LBW) by maternal age, period of birth, and maternal birth cohort (based on ageperiod-cohort models) among singleton, term live births in the U.S. from 1989–2010 (n=67,552,524)

Appendix E. Probabilities of preterm birth (PTB) by maternal age, period of birth, and maternal birth cohort (based on age-period-cohort models) among singleton live births in the U.S. from 1989–2010 (n=75,265,369)

Appendix F. Percent term small for gestational age (<10th percentile of weight for age) by age, period, and cohort among singleton, term (≥37 weeks gestation) live births to non-Hispanic black mothers from 1989–2010 in the US (n=9,849,337)

Figure 1. Probability of small for gestational age (SGA) by maternal birth cohort (based on age-period-cohort models) among singleton, term live births in the U.S. from 1989–2010 (n=67,552,524).

Figure 2. Probability of small for gestational age (SGA) by maternal age (based on age-period-cohort models) among singleton, term live births in the U.S. from 1989–2010 (n=67,552,524).

Figure 3. Probability of small for gestational age (SGA) by period of birth (based on age-periodcohort models) among singleton, term live births in the U.S. from 1989–2010 (n=67,552,524).

Figure 4. Probability of small for gestational age (SGA) by birth cohort (based on age-periodcohort models) among singleton, term live births to U.S.- and foreign-born non-Hispanic black mothers in the U.S. from 1989–2010.

Table 1a

Proportion small for gestational age (<10th percentile of weight for age) among singleton, term (≥ 37 weeks gestation) live births to foreign-born Hispanic mothers from 1989–2010 in the US (n=8,903,353), by maternal age and birth cohort.

Birth cohort	Maternal age							
	<15	15–19	20–24	25–29	30–34	35–39	40–44	>44
1944–1949							0.094	0.115
1950–1954						0.087	0.087	0.108
1955–1959					0.083	0.081	0.089	0.110
1960–1964				0.091	0.080	0.077	0.090	0.117
1965–1969			0.113	0.089	0.077	0.080	0.093	0.115
1970–1974		0.143	0.109	0.085	0.079	0.082	0.095	
1975–1979	0.178	0.141	0.110	0.088	0.082	0.084		
1980–1984	0.185	0.143	0.111	0.092	0.087			
1985–1989	0.166	0.139	0.114	0.094				
1990–1994	0.166	0.140	0.112					
1995–1999	0.164	0.144						

Table 1b

Proportion of small for gestational age (<10th percentile of weight for age) by maternal age and birth cohort, among singleton, term (≥ 37 weeks gestation) live births to US-born Hispanic mothers from 1989–2010 in the US (n=5,451,567), by maternal age and birth cohort.

Birth cohort	Maternal age							
	<15	15–19	20–24	25–29	30–34	35–39	40–44	>44
1944–1949							0.113	0.147
1950–1954						0.102	0.102	0.134
1955–1959					0.101	0.100	0.113	0.126
1960–1964				0.109	0.098	0.096	0.110	0.121
1965–1969			0.122	0.102	0.089	0.092	0.107	0.094
1970–1974		0.147	0.117	0.093	0.087	0.090	0.114	
1975–1979	0.159	0.145	0.113	0.095	0.090	0.093		
1980–1984	0.159	0.142	0.115	0.100	0.093			
1985–1989	0.165	0.145	0.122	0.104				
1990–1994	0.164	0.148	0.124					
1995–1999	0.163	0.148						

Table 1c

Proportion of small for gestational age (<10th percentile of weight for age) by maternal age and birth cohort, among singleton, term (37 weeks gestation) live births to non-Hispanic black mothers from 1989–2010 in the US (n=9,849,337), by maternal age and birth cohort.

Birth cohort	Maternal age							
	<15	15–19	20–24	25–29	30–34	35–39	40–44	>44
1944–1949							0.165	0.180
1950–1954						0.163	0.174	0.186
1955–1959					0.176	0.171	0.176	0.199
1960–1964				0.178	0.169	0.161	0.167	0.172
1965–1969			0.189	0.169	0.150	0.148	0.163	0.172
1970–1974		0.207	0.179	0.150	0.138	0.143	0.158	
1975–1979	0.226	0.206	0.173	0.148	0.141	0.138		
1980–1984	0.228	0.209	0.180	0.160	0.147			
1985–1989	0.229	0.213	0.191	0.164				
1990–1994	0.234	0.222	0.199					
1995–1999	0.247	0.229						

Table 1d

Proportion of small for gestational age (<10th percentile of weight for age) by maternal age and birth cohort, among singleton, term (37 weeks gestation) live births to non-Hispanic white mothers from 1989–2010 in the US (n=43,348,267), by maternal age and birth cohort.

Birth cohort	Maternal age									
	<15	15–19	20–24	25–29	30–34	35–39	40–44	>44		
1944–1949							0.085	0.102		
1950–1954						0.075	0.082	0.095		
1955–1959					0.074	0.075	0.081	0.096		
1960–1964				0.082	0.072	0.073	0.079	0.097		
1965–1969			0.103	0.078	0.067	0.068	0.081	0.098		
1970–1974		0.129	0.102	0.076	0.065	0.070	0.082			
1975–1979	0.136	0.130	0.103	0.076	0.070	0.074				
1980–1984	0.143	0.133	0.105	0.083	0.074					
1985–1989	0.140	0.133	0.112	0.086						
1990–1994	0.138	0.138	0.115							
1995–1999	0.136	0.139								

Table 2

Estimated probabilities and 95% confidence intervals (CI) from age, period, and cohort models of small for gestational age (SGA) among singleton, term live births in the U.S. from 1989–2010 (n=67,552,524), stratified by race/ethnicity/nativity.

	Probability of term SGA			
	Foreign-born Hispanic	US-born Hispanic	Non-Hispanic Black	Non-Hispanic White
Maternal age				
<15	0.17 [0.16, 0.18]	0.16 [0.15, 0.18]	0.24 [0.23, 0.25]	0.14 [0.14, 0.15]
15–19	0.14 [0.14, 0.14]	0.15 [0.14, 0.15]	0.22 [0.22, 0.23]	0.14 [0.13, 0.14]
20–24	0.11 [0.11, 0.11]	0.12 [0.11, 0.13]	0.19 [0.18, 0.19]	0.11 [0.11, 0.11]
24–29	0.09 [0.09, 0.09]	0.10 [0.09, 0.11]	0.16 [0.16, 0.17]	0.08 [0.08, 0.08]
30–34	0.08 [0.08, 0.08]	0.09 [0.09, 0.10]	0.16 [0.15, 0.16]	0.07 [0.07, 0.07]
35–39	0.08 [0.08, 0.08]	0.10 [0.09, 0.10]	0.16 [0.16, 0.16]	0.07 [0.07, 0.08]
40–44	0.09 [0.09, 0.03]	0.11 [0.10, 0.12]	0.18 [0.17, 0.18]	0.08 [0.08, 0.09]
>44	0.11 [0.10, 0.12]	0.13 [0.11, 0.14]	0.20 [0.18, 0.21]	0.10 [0.10, 0.11]
Period of birth				
1989	0.11 [0.10, 0.11]	0.12 [0.11, 0.13]	0.17 [0.16, 0.17]	0.09 [0.09, 0.10]
1990	0.11 [0.10, 0.11]	0.11 [0.11, 0.12]	0.17 [0.16, 0.18]	0.09 [0.09, 0.10]
1991	0.11 [0.10, 0.11]	0.12 [0.11, 0.13]	0.18 [0.17, 0.19]	0.10 [0.09, 0.10]
1992	0.11 [0.10, 0.11]	0.12 [0.11, 0.13]	0.18 [0.18, 0.19]	0.10 [0.10, 0.10]
1993	0.11 [0.10, 0.11]	0.12 [0.11, 0.13]	0.19 [0.18, 0.20]	0.10 [0.10, 0.10]
1994	0.11 [0.10, 0.11]	0.12 [0.11, 0.13]	0.20 [0.19, 0.20]	0.10 [0.10, 0.10]
1995	0.11 [0.10, 0.11]	0.12 [0.12, 0.13]	0.20 [0.20, 0.21]	0.10 [0.10, 0.11]
1996	0.11 [0.10, 0.11]	0.12 [0.12, 0.13]	0.21 [0.20, 0.21]	0.11 [0.10, 0.11]
1997	0.11 [0.10, 0.11]	0.12 [0.12, 0.13]	0.20 [0.20, 0.21]	0.10 [0.10, 0.11]
1998	0.10 [0.10, 0.11]	0.12 [0.11, 0.13]	0.20 [0.20, 0.21]	0.10 [0.10, 0.10]
1999	0.10 [0.10, 0.10]	0.12 [0.11, 0.12]	0.20 [0.19, 0.20]	0.10 [0.10, 0.10]
2000	0.10 [0.10, 0.10]	0.12 [0.11, 0.12]	0.20 [0.19, 0.20]	0.10 [0.10, 0.10]
2001	0.10 [0.10, 0.10]	0.12 [0.11, 0.12]	0.19 [0.19, 0.20]	0.10 [0.10, 0.10]
2002	0.10 [0.10, 0.10]	0.12 [0.11, 0.12]	0.19 [0.19, 0.20]	0.10 [0.10, 0.10]
2003	0.10 [0.10, 0.11]	0.12 [0.11, 0.12]	0.19 [0.19, 0.20]	0.10 [0.09, 0.10]
2004	0.10 [0.10, 0.11]	0.12 [0.11, 0.13]	0.19 [0.18, 0.20]	0.10 [0.09, 0.10]
2005	0.11 [0.10, 0.11]	0.12 [0.11, 0.12]	0.18 [0.18, 0.19]	0.09 [0.09, 0.10]
2006	0.11 [0.10, 0.11]	0.12 [0.11, 0.12]	0.18 [0.18, 0.19]	0.09 [0.09, 0.10]
2007	0.10 [0.10, 0.11]	0.11 [0.11, 0.12]	0.17 [0.17, 0.18]	0.09 [0.09, 0.10]
2008	0.11 [0.10, 0.11]	0.11 [0.10, 0.12]	0.17 [0.17, 0.18]	0.09 [0.09, 0.10]
2009	0.11 [0.10, 0.11]	0.11 [0.10, 0.12]	0.16 [0.16, 0.17]	0.09 [0.09, 0.09]
2010	0.11 [0.11, 0.12]	0.11 [0.10, 0.12]	0.16 [0.16, 0.17]	0.09 [0.09, 0.10]
Maternal birth cohort				
1940	0.10 [0.06, 0.15]	0.11 [0.04, 0.24]	0.18 [0.12, 0.25]	0.12 [0.10, 0.14]
1942	0.10 [0.09, 0.12]	0.12 [0.10, 0.12]	0.19 [0.12, 0.21]	0.10 [0.10, 0.11]
1944	0.11 [0.10, 0.12]	0.13 [0.11, 0.14]	0.21 [0.20, 0.22]	0.10 [0.10, 0.11]

Probability of term SGA				
	Foreign-born Hispanic	US-born Hispanic	Non-Hispanic Black	Non-Hispanic White
1946	0.11 [0.10, 0.11]	0.13 [0.11, 0.15]	0.23 [0.21, 0.24]	0.11 [0.10, 0.11]
1948	0.11 [0.10, 0.11]	0.13 [0.11, 0.14]	0.22 [0.21, 0.23]	0.10 [0.10, 0.11]
1950	0.11 [0.10, 0.11]	0.12 [0.11, 0.14]	0.21 [0.20, 0.22]	0.10 [0.10, 0.10]
1952	0.10 [0.10, 0.11]	0.12 [0.11, 0.13]	0.12 [0.19, 0.21]	0.10 [0.09, 0.10]
1954	0.10 [0.10, 0.11]	0.12 [0.11, 0.13]	0.19 [0.18, 0.20]	0.09 [0.09, 0.10]
1956	0.10 [0.10, 0.11]	0.12 [0.10, 0.13]	0.18 [0.17, 0.19]	0.09 [0.09, 0.09]
1958	0.10 [0.10, 0.11]	0.11 [0.10, 0.12]	0.17 [0.17, 0.18]	0.09 [0.09, 0.09]
1960	0.10 [0.10, 0.11]	0.11 [0.10, 0.12]	0.17 [0.16, 0.17]	0.09 [0.09, 0.09]
1962	0.10 [0.10, 0.11]	0.11 [0.10, 0.12]	0.16 [0.16, 0.17]	0.09 [0.09, 0.09]
1964	0.11 [0.10, 0.11]	0.11 [0.10, 0.12]	0.16 [0.15, 0.17]	0.09 [0.09, 0.09]
1966	0.11 [0.10, 0.11]	0.11 [0.10, 0.12]	0.16 [0.15, 0.16]	0.09 [0.09, 0.09]
1968	0.11 [0.10, 0.11]	0.11 [0.10, 0.12]	0.16 [0.15, 0.16]	0.09 [0.09, 0.09]
1970	0.11 [0.11, 0.11]	0.11 [0.10, 0.12]	0.16 [0.15, 0.16]	0.09 [0.09, 0.09]
1972	0.11 [0.11, 0.11]	0.11 [0.10, 0.12]	0.16 [0.16, 0.17]	0.09 [0.09, 0.09]
1974	0.11 [0.11, 0.12]	0.11 [0.11, 0.12]	0.17 [0.16, 0.17]	0.09 [0.09, 0.09]
1976	0.11 [0.11, 0.11]	0.11 [0.11, 0.12]	0.17 [0.16, 0.17]	0.09 [0.09, 0.10]
1978	0.11 [0.11, 0.11]	0.12 [0.11, 0.12]	0.17 [0.17, 0.18]	0.10 [0.09, 0.10]
1980	0.11 [0.11, 0.11]	0.12 [0.11, 0.12]	0.18 [0.17, 0.18]	0.10 [0.10, 0.10]
1982	0.11 [0.11, 0.11]	0.12 [0.11, 0.12]	0.18 [0.18, 0.19]	0.10 [0.10, 0.10]
1984	0.11 [0.11, 0.11]	0.12 [0.12, 0.13]	0.19 [0.19, 0.20]	0.10 [0.10, 0.11]
1986	0.11 [0.11, 0.11]	0.12 [0.12, 0.13]	0.20 [0.19, 0.20]	0.10 [0.10, 0.11]
1988	0.11 [0.10, 0.11]	0.12 [0.12, 0.13]	0.20 [0.20, 0.21]	0.11 [0.10, 0.11]
1990	0.11 [0.10, 0.11]	0.13 [0.12, 0.13]	0.21 [0.21, 0.22]	0.11 [0.10, 0.11]
1992	0.10 [0.10, 0.11]	0.13 [0.12, 0.13]	0.22 [0.21, 0.23]	0.11 [0.10, 0.11]
1994	0.10 [0.10, 0.11]	0.12 [0.11, 0.13]	0.22 [0.21, 0.23]	0.10 [0.10, 0.11]
1996	0.09 [0.07, 0.12]	0.12 [0.09, 0.14]	0.20 [0.18, 0.23]	0.09 [0.08, 0.11]