Original article

Strong upward neighborhood mobility and preterm birth: a matched-sibling design approach

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A B S T R A C T

Purpose: Much cross-sectional work reports an association between neighborhood disadvantage and adverse birth outcomes. Limitations of this work include that mothers with pre-existing unmeasured morbidity may "select" into, or out of, certain neighborhoods. This selection issue remains a key rival explanation for work concerned with place-based disparities in birth outcomes. We move beyond a cross-sectional approach and exploit a sibling-linked data set in California to test whether upwardly mobile mothers, who move from a very high to a very low disadvantaged neighborhood, exhibit a lower than expected risk of preterm birth (PTB) (i.e., delivery <37 weeks).
Methods: We used a matched-sibling design for 461,061 sibling pairs (i.e., 922,122 births total) to mothers in urban areas in who gave birth in California from 2005 to 2010. We linked mother's address at two time points (i.e., two sibling birth dates) to a census-derived composite indicator of neighborhood disadvantage. Conditional logistic regression methods controlled for mother's risk of PTB in the sibling delivered before the move when estimating the relation between strong upward mobility and preterm of the subsequent birth after the move.
Results: As hypothesized, strong upward mobility (relative to no mobility) varies inversely with the odds of PTB of the second sibling (odds ratio [OR] for PTB = 0.83, 95% confidence interval: 0.74, 0.93).
Conclusions: Mothers moving from very high to very low disadvantaged neighborhoods show a reduced odds of PTB. Our findings, if replicated, raise the possibility that improvements in neighborhood quality may improve perinatal health in a relatively short time span.

Introduction

Extensive literature reports positive associations between residence in a disadvantaged neighborhood and adverse health. The literature on birth outcomes, for instance, includes a meta-analysis of over 1500 articles over a 20-year period on this topic [1]. Preterm birth (PTB; delivery <37 weeks of gestation) represents one important birth outcome which occurs more frequently in neighborhoods characterized as disadvantaged [2–4]. PTB in the United States accounts for almost 10% of births in the US but over 50% of infant deaths [5]. In addition, preterm infants who survive beyond the first year show an increased risk of developmental disorders, reduced educational attainment, and reduced earnings in adulthood [5].

Given the life-course sequelae of PTB, and its association with neighborhood disadvantage, scholars from a diverse set of fields have proposed hypotheses by which neighborhood disadvantage may affect PTB. Although definitions of neighborhood disadvantage vary, most scholars operationalize this construct through aggregate-level indicators of concentrated poverty, disinvestment in public resources, and lack of economic opportunity in a defined geographic area [6]. A few (but by no means exhaustive) proposed pathways by which neighborhood disadvantage may affect PTB and other birth outcomes include elevated stress during pregnancy, peer norms that increase alcohol, tobacco, and other drug

consumption, low-quality housing conditions, ambient air pollution, lack of access to healthy food, and reduced access to health care and other services [1].

If one assumes that neighborhood disadvantage adversely affects perinatal health, then mothers who move away from these areas and into low-disadvantage neighborhoods may show perinatal health improvements. Scholars, however, note that the cross-sectional nature of research comparing birth outcomes of mothers in high-disadvantage and low-disadvantage neighborhoods precludes establishment of a causal relation [7,8]. Cross-sectional study designs cannot rule out the rival of "neighborhood selection" in which healthier women, over time, move to less disadvantaged neighborhoods [9]. Similarly, women with relatively worse health may have limited access to economic resources and therefore remain in these areas despite wanting to move away from disadvantage [6]. To the extent that these moves (or lack thereof) correlate with factors that affect maternal and perinatal health, the nonrandom selection of persons into neighborhoods may strongly bias the relation between neighborhood disadvantage and birth outcomes [10].

We contribute to the literature by moving beyond cross-sectional approaches to examine the relation between neighborhood disadvantage and PTB. We exploit a unique sibling-linked data set of over 900,000 births in California which allows us to track a mother's residence, and her birth outcomes, over two time points. Our matched-sibling design strategy [11] holds two advantages relative to previous work. First, we identify a unique set of upwardly mobile mothers who move from a very-high to a very-low disadvantage neighborhood. If characteristics of this new neighborhood confer health benefits to the mother, such upward neighborhood mobility may reduce the risk of PTB. Second, the sibling design approach permits adjustment for relatively stable baseline maternal health and social factors that influence preterm risk. The logic of this strategy involves using the PTB outcome of a sibling born in the mother's former neighborhood to control for unmeasured maternal factors that correlate with both her ability to move and the risk of PTB for the current newborn.

We hypothesize that women who show strong upward mobility, by moving from a very-high to a very-low disadvantage urban neighborhood, will show a lower than expected risk of delivering a preterm infant. These strong upwardly mobile mothers, unlike most persons living in a disadvantaged context [9], do not experience persistence in their exposure to disadvantage. We exploit this unique opportunity to assess the salience of very-low-disadvantage neighborhoods on the risk of PTB.

We test our hypothesis using mothers with at least two live births in California from 2005 to 2010. Given that researchers have validated the disadvantage index only in urban areas, we focus our analysis on mothers residing in urban census tracts. We also examine as a secondary outcome small-for-gestational age (SGA), which is a proxy for growth restriction independent of the gestational age at delivery [12]. California accounts for over 15% of all births in the United States and includes a high degree of diversity in terms of racial/ethnic and socioeconomic composition. Importantly, the California data set includes information on the PTB (and SGA) status of the index sibling born before the move. This information permits baseline control for time invariant, unmeasured health characteristics related to the mother's risk of delivering a preterm infant through a conditional logistic regression framework.

Methods

Variables and data

We retrieved birth data from the California Department of Public Health birth files for years 2005–2010 [13]. This time span represents the longest series of data years, with the requisite variables to perform our tests, available to us at the time of the analysis. The birth file contains over 99.99% of all live births in California (2005–2010 N = 3,517,193) and includes health and demographic information collected from the certificate of birth. Previous reports describe the quality and provenance of the data [14,15]. Importantly, the birth file contains mother's home address at the time of birth, which permits linkage of neighborhood disadvantage variables (described in the following). The State of California and the University of California, Irvine, approved the study (IRB protocol approval # 13-06-1251 and 2013-9716, respectively).

Sibling linkage strategy

We excluded mothers with nonsingleton births (N = 329,177). We then used a probabilistic linkage strategy to identify consecutive singleton live births to the same mother from January 2005 through December 2010. We performed record linkages using Link Plus (version 2.0), an open-source probabilistic record linkage program developed at the Division of Cancer Prevention within the Centers for Disease Control and Prevention. Link Plus computes linkage scores based on a theoretical framework [16]. The program first identifies potential matches by "blocking" pairs of records with exact values on a specified field. Comparison-pairs receive a match score based on similarity of specified "match" variables. Pairs with higher scores appear more likely to reflect "true" matches. The user sets an upper-bound score above which all pairs receive a "true" match designation.

We used Link Plus to "block" records based on maternal date of birth. Pairs then received a match score according to similarity of maternal first and last name, in addition to maternal date of birth. We set the upper-bound score at 15.0, at or above which comparison-pairs share a common maternal date of birth, last name, and first name. We rejected pairs of women with different last names, corresponding to match scores below 12.0. We conducted a manual review of pairs with match scores between 12.0 and 14.9 and additionally compared infant date of birth (in record 1) with date of last delivery (in record 2). We coded records with corresponding dates for last delivery (in record 2) and infant birth (in record 1) as matches. This process left us with an analytic sample of 752,298 sibling pairs (i.e., 1,504,596 births total).

Geocoding

We geocoded maternal residential address of mothers at first birth and second birth using ArcGIS software version 10.4 (Redlands, California). We located maternal addresses using a 2013 street directory and assigned a corresponding census tract (a proxy of neighborhood) based on 2010 US Census geography. We excluded birth records with maternal addresses that failed to reach a minimum location match score of 80 percent or with unknown, missing, or non-California census tracts at first birth (N = 58,231 births) and second birth (N = 53,134 births). Excluding sibling pairs with invalid/missing census tract data at either birth (N = 96,231 pairs), as well as sibling pairs in nonurban tracts and/or with missing data on key covariates (N = 195,036 pairs), left us with a final analytic sample of 461,031 sibling pairs (Fig. 1).

We used neighborhood disadvantage, measured at the census tract level, as our key independent variable [6]. We calculated a neighborhood disadvantage index using six variables taken from the 2010 U.S. Decennial Census: the proportion of households with income <$15,000, the proportion of households with income ≥$50,000 (reverse coded), the proportion of families in poverty, the proportion of households receiving public assistance, the total unemployment rate, and the proportion of vacant housing units
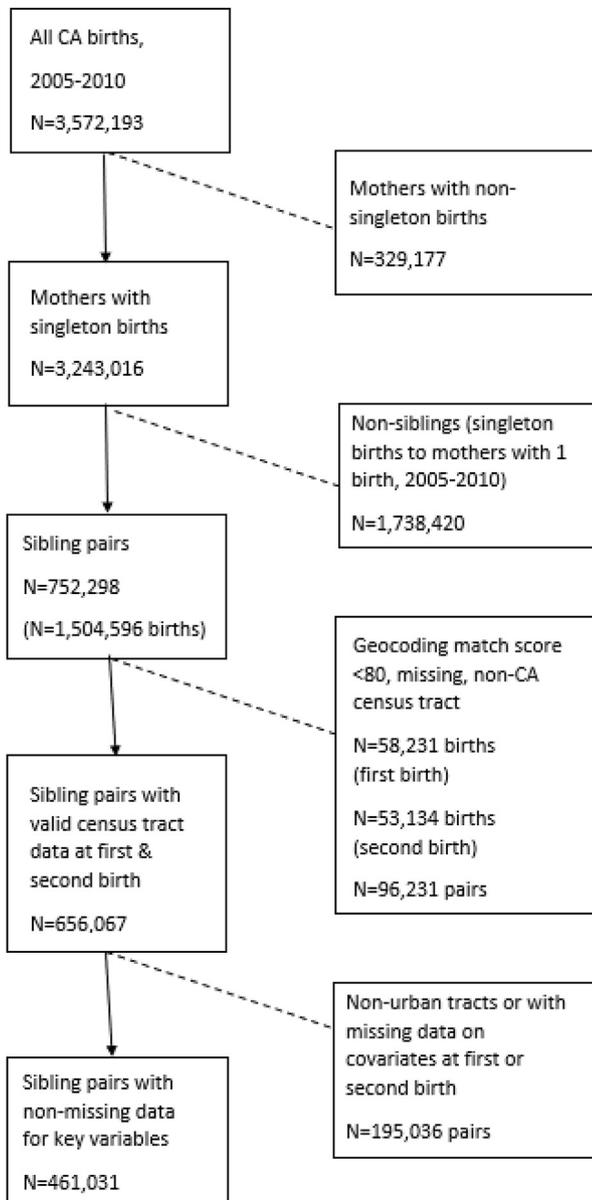
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All CA births,
2005-2010
N=3,572,193
          ┄┄┄┄┄┄┄►  Mothers with non-
                    singleton births
                    N=329,177
Mothers with
singleton births
N=3,243,016
          ┄┄┄┄┄┄┄►  Non-siblings (singleton
                    births to mothers with 1
                    birth, 2005-2010)
                    N=1,738,420
Sibling pairs
N=752,298
(N=1,504,596 births)
          ┄┄┄┄┄┄┄►  Geocoding match score
                    <80, missing, non-CA
                    census tract
                    N=58,231 births
                    (first birth)
                    N=53,134 births
                    (second birth)
                    N=96,231 pairs
Sibling pairs with
valid census tract
data at first &
second birth
N=656,067
          ┄┄┄┄┄┄┄►  Non-urban tracts or with
                    missing data on
                    covariates at first or
                    second birth
                    N=195,036 pairs
Sibling pairs with
non-missing data
for key variables
N=461,031
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Fig. 1. Sample selection process for 461,031 sibling pairs in California, 2005−2010.

(Cronbach's alpha = 0.92). We standardized each variable and then constructed the index by taking the average value of the standardized variables. The value of the index can be interpreted as the number of standard deviations away from the California state urban mean level.

To avoid imposing an assumption of linearity on the association between neighborhood disadvantage and PTB, we calculated quartiles of the index (1 = very low, 2 = low, 3 = high, 4 = very high). To give the reader a sense of geographic variation in disadvantage, Figure 2 maps neighborhood disadvantage for tracts in Los Angeles County, which accounts for over a quarter of all births in California during the test period.

Past research has used a neighborhood deprivation index (NDI) to link the neighborhood social environment to PTB [2,17,18]. The NDI includes indicators of education, occupational prestige, poverty, and income. The Pearson correlation between the NDI and the neighborhood disadvantage index in our data is 0.95, suggesting extremely similar (if not identical) results would emerge had

we utilized the NDI. We do not use the NDI as several recent studies show that indicators of education and occupational prestige differ conceptually from those of poverty, income, and employment, and should therefore be considered as distinct indices [19,20].

Based on the sibling link and the geocoding of maternal addresses for each of the consecutive live births, we calculated a neighborhood mobility score. First, using mother's address at infant's live birth, we categorized the neighborhood disadvantage index into quartiles. Quartile 4 (Q4) represents the quartile with the highest disadvantage, and Q1 represents the quartile with the lowest disadvantage. Second, we categorized mothers by the level of neighborhood mobility away from, or into, disadvantage using the two time points of neighborhood information (i.e., index sibling and subsequent sibling, from 2005 to 2010). We created categorical variables for upward, downward, and no mobility. Strong upward mobility captures a move of three quartiles magnitude away from disadvantage (i.e., move from Q4 to Q1), whereas moderate upward mobility and low upward mobility capture a move of two quartiles, and one quartile, away from disadvantage, respectively. We coded downward mobility in a similar fashion to upward mobility but in the inverse (i.e., move from Q1 to Q4 is strong downward mobility). We coded mothers who show no upward or downward mobility as "no mobility." The "no mobility" category, however, does not require that a mother lists the same residential address for each birth. Mothers who move residence but do not change quartile of neighborhood disadvantage also qualify as "no mobility" given the essentially lateral nature of the move [18].

We used PTB as our key dependent variable, categorized as binary (yes/no). We, consistent with the literature, defined PTB as gestational age of less than 37 completed weeks at delivery (i.e., <259 days) [21]. We derived gestational age by using the clinical estimate of gestation on the birth certificate. Given that previous literature finds that intrauterine growth varies with characteristics of the social environment [22], we also examined SGA as a second dependent variable. SGA, defined categorically as birth weight below the 10th percentile for the given gestational age and sex (yes/no), serves as a clinical proxy for growth-restricted infants [23]. Perinatal epidemiologists have argued distinct etiologies of PTB and SGA, which indicates that these measures may respond differently to the social environment [12].

Analysis

Our test turns on whether the risk of PTB falls below expected values when mothers exhibit strong upward neighborhood mobility. Healthier mothers, however, with a lower risk of a PTB may show stronger upward mobility than would less-healthy mothers. We addressed this selection issue by controlling for PTB in the mother's first pregnancy before mobility. This matched-sibling design strategy minimizes time-invariant confounding, such as mother's overall health (or, for instance, race/ethnicity, education level), which affects the risk of PTB equally across consecutive births [24]. Our strategy, also referred to as mother "fixed effects," exploits within-mother variation in the risk of PTB.

The logic of the sibling control strategy led us to estimate the conditional logit (i.e., log-odds) of PTB (yes/no) of the second sibling as a function of the PTB status of the index sibling and of the mother's neighborhood mobility score. We also inserted as control variables several time-varying characteristics of the mother as well as birth characteristics of the second sibling that reportedly affect the risk of PTB [25]. These variables include maternal age at birth of second infant (categorized as <20, 20−24, 25−29, 30−34, 35−39, 40+ years), expected payer for delivery (private insurance/ Medicaid/other), parity, and infant sex. We then repeated the
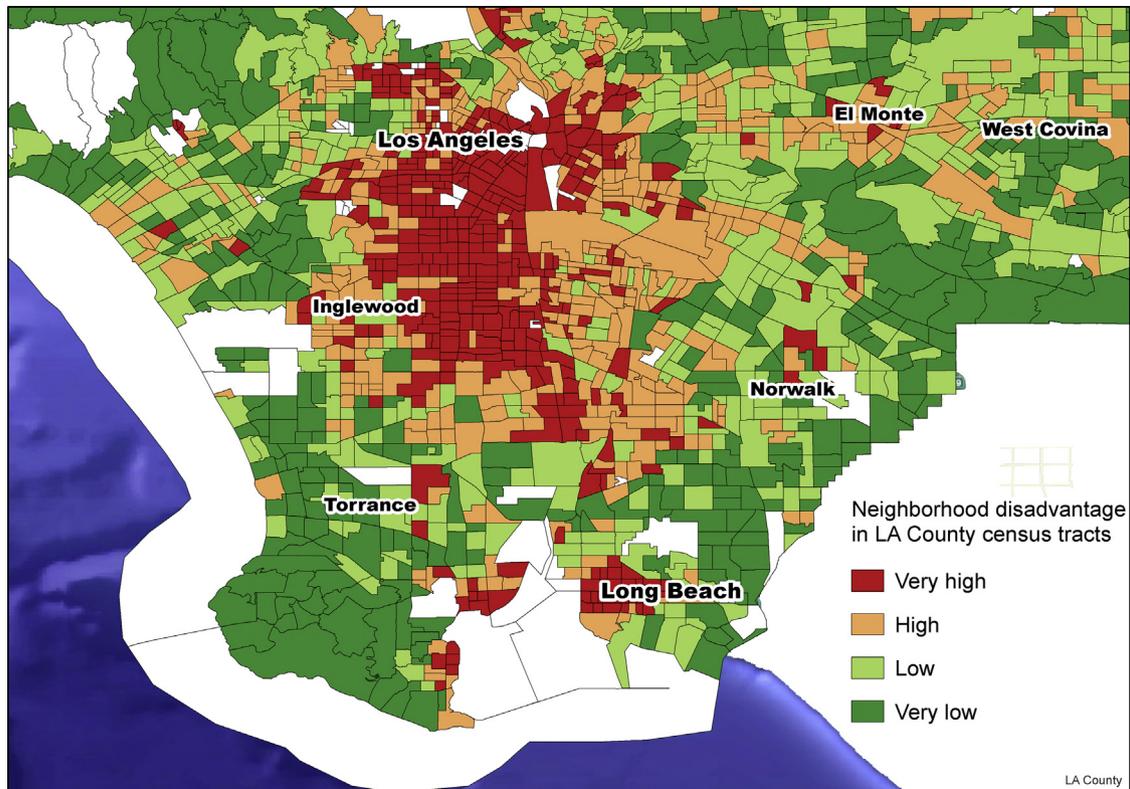
Fig. 2. Map of neighborhood disadvantage in census tracts of Los Angeles County, California.

analysis but replaced PTB with SGA (yes/no) as the dependent variable. We conducted all analyses in SAS 9.4 (Cary, North Carolina).

Results

Table 1 describes maternal and infant characteristics of our analytic sample. Table 2 arrays the 461,061 mothers by quartile of neighborhood disadvantage according to the disadvantage scores of their neighborhood of residence at time 1 (i.e., index birth, horizontal axis) and time 2 (second sibling birth, vertical axis). The main diagonal indicates no mobility in that a woman's neighborhood of residence over the two recorded births remains within the same quartile of disadvantage.

Almost 29% of women show mobility as indicated by off-diagonal cells. For instance, 3812 women show strong upward mobility (upper right corner, from Q4 to Q1). Low and moderate mobility—both in the upward and downward direction—occurs more frequently than does strong mobility.

Table 3 displays the characteristics of the dependent variables by level of mobility. Consistent with the fact that ~70% of mothers show no mobility, most PTB cases appear in the no mobility category. The risk of PTB in any mobility category ranges from 8.47 to 10.95 per 100 births. The strong upward mobility category shows the lowest crude risk of PTB.

As hypothesized, strong upward mobility (relative to no mobility) varies inversely with the odds of PTB of the second sibling (odds ratio [OR] for PTB = 0.83, 95% confidence interval [CI]: 0.74, 0.93; see Table 4). More modest mobility changes, as well as strong downward mobility, show no relation with PTB. Other covariates yield coefficients that appear consistent with previous literature. Public health insurance (vs. private health insurance), for instance, varies positively with the odds of PTB, as does teenage pregnancy, older maternal age, PTB status of previous birth, and male infant sex [25,26].

Table 5 displays results predicting SGA of the second birth as a function of SGA of the index birth, neighborhood mobility, and covariates. We find no associations for any level of upward mobility.

Table 1
Maternal characteristics and birth outcomes at time 1 (first birth) and time 2 (second birth) for 461,061 mothers with consecutive singleton live births in California, 2005—2010

Maternal characteristics	Time 1		Time 2	
	n	%	n	%
Education				
Less than HS	137,813	29.89	117,174	25.42
High school	107,613	23.34	115,350	25.02
Some college	85,805	18.61	97,780	21.21
BA degree or more	116,243	25.21	116,056	25.17
Other	13,557	2.94	14,671	3.18
Payer				
MediCAL	219,233	47.55	220,858	47.91
Private	215,922	46.83	213,863	46.39
Other	25,876	5.61	26,310	5.71
Race/ethnicity				
NH white	122,238	26.51	122,054	26.47
NH black	29,921	6.49	29,534	6.41
NH Asian	62,664	13.59	62,589	13.58
Hispanic	237,596	51.54	237,649	51.55
Infant sex—male	235,782	51.14	236,203	51.23
Maternal age (y)				
<20	60,831	13.19	17,910	3.88
20—24	123,677	26.83	103,266	22.40
25—29	130,690	28.35	128,679	27.91
30—34	103,795	22.51	124,047	26.91
35—40	38,480	8.35	72,515	15.73
>40	3558	0.77	14,614	3.17
Birth outcomes				
PTB	45,951	9.97	46,302	10.04
SGA	49,913	10.83	37,808	8.20

Table 2
Preterm births per number of live births among 461,061 mothers in California at time 2, by quartile of neighborhood disadvantage at time 1 and quartile of neighborhood disadvantage at time 2

	Neighborhood disadvantage	Time 1			
		Q1	Q2	Q3	Q4
Time 2	Q1 (very low)	7.8% (6983/89,379)	8.2% (1139/13,907)	9.4% (778/8225)	8.5% (323/3812)
	Q2 (low)	8.6% (1320/15,326)	9.2% (7038/76,786)	9.5% (1346/14,184)	10.8% (960/8906)
	Q3 (high)	10.2% (724/7109)	10.1% (1608/15,935)	10.3% (7833/75,828)	12.1% (1991/16,473)
	Q4 (very high)	10.3% (357/3460)	11.6% (1002/8657)	12.0% (2033/16,986)	12.6% (10,867/86,058)

N = 461,061 mothers.
Q1 = low neighborhood disadvantage; Q4 = high neighborhood disadvantage.

By contrast, strong downward mobility varies with an increased odds of SGA (OR for SGA = 1.12, 95% CI: 0.995, 1.25), although the coefficient lies slightly outside conventional levels of statistical detection. (Descriptive statistics of SGA by mobility category appear in Appendix Table S1.)

We assessed whether the mobility results appeared robust to alternative specifications. First, to ensure that a "positivity violation" did not distort results [27], we removed several maternal covariates that rise monotonically with progressing from the index birth to the subsequent birth (i.e., parity, maternal age). Second, for the strong upward mobility coefficient (Table 3; preterm birth), we repeated the analysis using only the sample of mothers who initially resided in Q4 and therefore had the potential to exhibit strong upwardly mobile over time (i.e., move from Q4 to Q1 of neighborhood disadvantage). Inference from both sensitivity analyses remained essentially unchanged from the original tests (results available on request). We also explored the potential role of health selection in our PTB finding by examining whether strong upward mobility between births at times 1 and 2 predicted PTB risk of birth at time 1. Results (OR = 0.97, 95% CI: 0.87, 1.08) do not support that health selection explains the strong upwardly mobile/PTB result.

Discussion

Although much work reports cross-sectional associations between neighborhood conditions and adverse birth outcomes, nonrandom selection over time of individuals into place serves as a strong plausible threat to inferring any causal relation [1]. We improve on previous work by exploiting longitudinal information on maternal residence over two time points. We investigate the odds of PTB among California mothers who, from 2005 to 2010, moved from a neighborhood with high disadvantage to one with low disadvantage. We find that, controlling for mother's past risk of delivering preterm, the odds of PTB falls below expected levels following a strong upward move to a very low-disadvantage neighborhood. Upwardly mobile mothers show a reduced odds of

PTB. Although we cannot interpret results as causal, this finding supports the notion of malleability of maternal and child health, even within a span of a few years, which corresponds with reduced neighborhood disadvantage.

Strengths of the analysis include the large sample size of over 900,000 births, drawn from the population base of a diverse set of mothers in California, over a 6-year period. This circumstance indicates the population-representativeness of results while ensuring adequate statistical power to examine the subset of women (n = 3812) showing strong upward mobility. In addition, linkage of consecutive siblings by mother ID permits identification of neighborhood mobility over time while also controlling for mother's baseline risk of adverse birth outcomes before the move. This strategy, unlike earlier work [1], minimizes confounding due to selection of relatively healthier mothers into less disadvantaged neighborhoods.

Limitations include that results may not generalize to mothers with completed fertility of only one child or with longer interbirth interval spacing than the six-year time span for which we had data. Mothers with only one child may have unmeasured morbidities which correspond with subfecundity. For this reason, mothers with at least two children over the study interval may have different PTB risk relative to mothers with only one child. Supplemental analyses (Table S2 in Appendix), in fact, indicate lower PTB risk among mothers with two children relative to mothers with only one child, as well as differences in demographic composition and exposure to neighborhood disadvantage. These differences indicate that the matched-sibling design captures births with unknown external validity to the overall population of live births in California.

We also excluded mothers with missing data on key covariates. This exclusion may have introduced selection bias. However, we find a similar proportion of PTB (at first and second birth) among mothers with missing data on essential covariates and mothers with complete covariate data, which suggests limited bias because of sample restrictions.

Neighborhood mobility between births implies having the economic means and/or economic necessity to move, as well as

Table 3
Risk per 100 live births of preterm birth (<37 weeks' gestation) and small-for-gestational age (birthweight-for-gestational age <10th percentile) at time two by level of mother's neighborhood mobility, California, 2005 to 2010

Neighborhood mobility	Preterm birth		Small-for-gestational age	
	Cases	Cases per 100 live births	Cases	Cases per 100 live births
No change	32,721	9.97	26,335	8.03
Downward (inclusive)	7044	10.44	5942	8.81
Strong downward	357	10.32	337	9.74
Modest downward	1726	10.95	1418	8.99
Low downward	4961	10.28	4187	8.68
Upward (inclusive)	6537	9.98	5531	8.44
Low upward	4476	10.04	3824	8.58
Modest upward	1738	10.15	1404	8.20
Strong upward	323	8.47	303	7.95

Table 4
Odds ratios (OR)[*] and 95% confidence intervals (CI) predicting the probability of preterm birth at time 2 as a function of preterm birth at time 1, maternal mobility levels (vs. no change), and covariates

Parameter	OR (95% CI)
Preterm birth (time 1)	2.98 (2.90, 3.05)
Mobility	
Strong upward	0.83 (0.74, 0.93)
Modest upward	1.02 (0.96, 1.07)
Low upward	0.99 (0.95, 1.02)
No change (ref)	
Low downward	0.99 (0.96, 1.03)
Modest downward	1.04 (0.99, 1.09)
Strong downward	0.96 (0.86, 1.07)
Insurance	
Private (ref)	
Public	1.28 (1.25, 1.30)
Other	1.26 (1.21, 1.32)
Parity	
1 birth	0.88 (0.81, 0.95)
2 births	0.76 (0.75, 0.78)
3+ births (ref)	
Infant male (time 1)	1.03 (1.01, 1.05)
Infant male (time 2)	1.16 (1.14, 1.18)
Maternal age (y)	
<20	1.29 (1.23, 1.35)
20–24 (ref)	
25–29	0.90 (0.87, 0.92)
30–34	0.86 (0.84, 0.89)
35–39	0.94 (0.91, 0.97)
≥40	1.15 (1.09, 1.22)

[*] All odds ratios in the table are adjusted for all other variables in the model.

making the actual move. Each of these processes could affect the risk of PTB. For instance, mothers who move (i.e., upward or downward) show a slightly lower risk of PTB relative to nonmovers (results available on request). We, however, do not have

Table 5
Odds ratios (OR)[*] and 95% confidence intervals (CI) predicting the probability of small-for-gestational age (SGA) at time 2 as a function of small-for-gestational age at time 1, maternal mobility levels (vs. no change), and covariates

Parameter	OR (95% CI)
SGA (time 1)	4.04 (3.94, 4.14)
Mobility	
Strong upward	0.95 (0.84, 1.07)
Modest upward	0.99 (0.93, 1.04)
Low upward	1.03 (1.00, 1.07)
No change (ref)	
Low downward	1.03 (1.00, 1.07)
Modest downward	1.05 (0.99, 1.11)
Strong downward	1.12 (0.995, 1.25)
Insurance	
Private (ref)	
Public	1.22 (1.19, 1.25)
Other	1.21 (1.16, 1.27)
Parity	
1 birth	1.45 (1.34, 1.56)
2 births	0.98 (0.96, 1.00)
3+ births (ref)	
Infant male (time 1)	1.03 (1.01, 1.05)
Infant male (time 2)	1.00 (0.98, 1.02)
Maternal age (y)	
<20	1.13 (1.07, 1.19)
20–24 (ref)	
25-29	0.90 (0.87, 0.92)
30-34	0.84 (0.82, 0.87)
35-39	0.81 (0.78, 0.84)
≥40	0.85 (0.79, 0.91)

[*] All odds ratios in the table are adjusted for all other variables in the model.

characteristics about the move or the causes of change in residence (e.g., new employment), nor do we have detailed data on the socioeconomic circumstances of the family unit [7]. For these reasons, we cannot identify potential mechanisms that may trigger mobility decisions and/or affect the subsequent health of mothers. Other aspects of maternal health—or of the father's situation—which we do not control for in adjusted analyses may also affect both mobility and birth outcomes. Owing to limited data on maternal health available in birth files, we cannot directly measure and control for these potential confounders. In addition, the California birth file is limited in that information on place of residence is missing non-randomly for a small fraction of mothers [28]. The file also contains some error in classification of gestational age [29].

The matched-sibling design, although useful in minimizing unobserved time-invariant confounding within-mother, may introduce selection bias [27]. This bias could arise from differences in the mobility/PTB relation between mothers with two children relative to mothers with one child over the test period. In addition, all second births in this sibling pair occurred to an older mother of higher parity, both of which tend to affect risk of PTB and SGA. Although we include these covariates in the model to absorb between-mother differences, the fixed effects approach cannot fully adjust for contribution of these factors to PTB/SGA.

Although we did not have an *a priori* hypothesis about downwardly mobile mothers, we find an association between strong downward mobility and SGA but not for PTB. A previous study of Chicago-born mothers which measured residence at two time points (i.e., mother's birthdate and her infant's birth date) reports adverse birth outcomes among downwardly economically mobile mothers [30]. The authors further find that the deterioration of a woman's status before, and during, the childbearing years appears to confer the greatest risk for the subset of mothers who themselves were low weight deliveries. We therefore speculate that the subset of downwardly mobile mothers in our sample who themselves were SGA may account for the observed association. We, however, caution the reader that this conjecture requires additional refinement and testing.

Much literature on birth outcomes includes hypotheses regarding neighborhood exposure to long-term adversity and stress. This work may lead some scholars to conclude that any acute responses to neighborhood change that we discovered may arise from unmeasured characteristics of the mother that induce an upward move, rather than from a "true" neighborhood effect. Additional data collection on these mothers, as well as aspects of the neighborhood that scholars consider salubrious, would help distinguish between these explanations. We also note that the literature documents relatively acute perinatal health responses to changes in the ambient environment [31–33], which raises the possibility that pregnancy appears sensitive to both short-term and long-term neighborhood exposures.

Given the rarity of strong upward mobility in our sample, the population-level influence of moving from a high disadvantage to a low disadvantage neighborhood on PTB remains modest. We, however, view our results as important for two reasons. First, the magnitude of the reduction in odds of PTB for the strongly upwardly mobile group is not small. Second, results in this group indicate that perinatal health may improve, over a relatively short time frame, among mothers initially living in a highly disadvantaged neighborhood. This possibility runs counter to research on smaller intergenerational data sets which find no improvements in perinatal health among women born preterm or low weight into high-poverty areas [34,35]. We encourage replication of our results as well as additional longitudinal research to identify which aspects of the neighborhood, or of these upwardly mobile women, improve the health of her subsequent pregnancy.

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Appendix

Table S1
Small-for-gestational age (SGA) births per number of live births among mothers in California at time 2, by quartile of neighborhood disadvantage at time 1 and quartile of neighborhood disadvantage at time 2

	Neighborhood disadvantage	Time 1			
		Q1	Q2	Q3	Q4
Time 2	Q1 (very low)	6.8% (6048/89,379)	7.3% (1013/13,907)	7.7% (634/8225)	7.9% (303/3812)
	Q2 (low)	7.4% (1136/15,326)	7.5% (5774/76,786)	8.1% (1160/14,184)	8.7% (770/8906)
	Q3 (high)	8.4% (596/7109)	8.5% (1352/15,935)	8.2% (6214/75,828)	10.0% (1651/16,473)
	Q4 (very high)	9.7% (337/3460)	9.8% (849/8657)	10.0% (1699/16,986)	9.6% (8299/86,058)

N = 461,061 mothers.
Q1 = low neighborhood disadvantage; Q4 = high neighborhood disadvantage.

Table S2
Maternal characteristics and birth outcomes for mothers with consecutive live births at time 2 (N = 461,031) and non-consecutive live births (i.e. non-siblings) in California, 2005−2010 (N = 2,067,597)

Maternal characteristics	Mothers with 2+ live births, N (%)	Mothers with 1 live birth, N (%)
Education		
Less than HS	117,174 (25.4)	586,256 (28.4)
High school	115,350 (25.0)	510,589 (24.7)
Some college	97,780 (21.2)	446,300 (21.6)
BA degree or more	116,056 (25.2)	455,201 (22.0)
Other	14,671 (3.2)	69,251 (3.4)
Payer		
MediCAL	220,858 (47.9)	980,488 (45.5)
Private	213,863 (46.4)	935,556 (45.3)
Other	26,310 (5.7)	151,553 (7.3)
Race/ethnicity		
NH white	122,054 (26.5)	536,560 (25.9)
NH black	29,534 (6.4)	115,610 (5.6)
NH Asian	62,589 (13.6)	262,213 (12.7)
Hispanic	237,649 (51.6)	1,109,185 (53.7)
Infant sex−male	236,203 (51.2)	1,058,944 (51.2)
Maternal age (y)		
<20	17,910 (3.9)	198,686 (9.6)
20−24	103,266 (22.4)	430,838 (20.8)
25−29	128,679 (27.9)	528,328 (25.5)
30−34	124,047 (26.9)	502,359 (24.3)
35−40	72,515 (15.7)	314,013 (15.2)
>40	14,614 (3.2)	92,634 (4.5)
Birth outcomes		
PTB	46,302 (10.0)	208,995 (10.4)
SGA	37,808 (8.2)	157,706 (7.6)
Neighborhood disadvantage		
Very low	115,323 (25.0)	124,382 (19.3)
Low	115,202 (25.0)	146,988 (22.8)
High	115,345 (25.0)	176,012 (27.3)
Very high	115,161 (25.0)	197,280 (30.6)