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Supplemental Material

Residential Proximity to Oil and Gas Development and Birth Outcomes in California: A Retrospective Cohort Study of 2006–2015 Births

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Supplemental Material

Figure S1. Active well density by air basin across California (2005–2015). Map created in ArcGIS 10.6 (ESRI, Redlands, CA). The well density was calculated via the point density tool, which calculates density based on the number of neighboring wells within a 1 km x 1 km cell around each well by air basin.

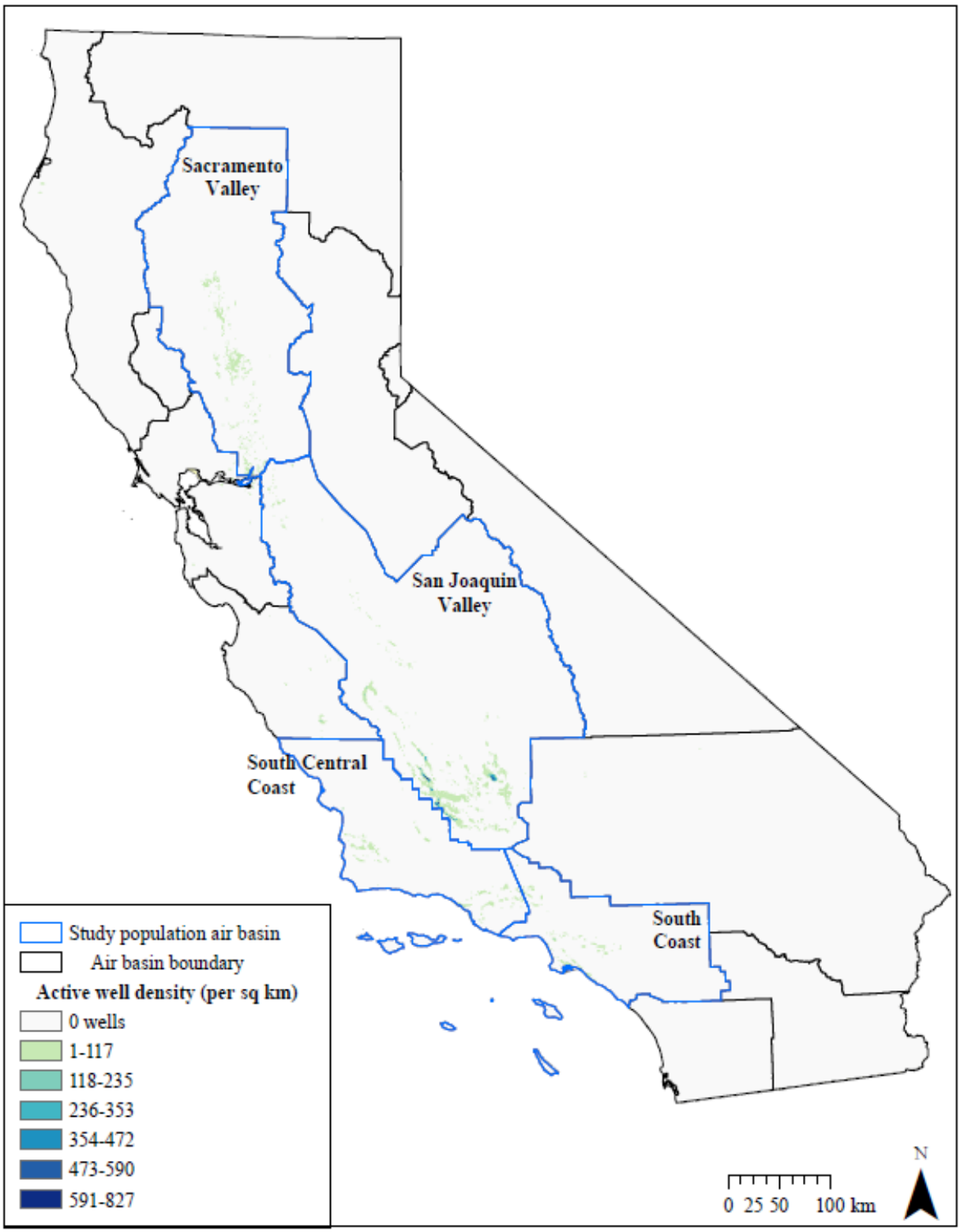
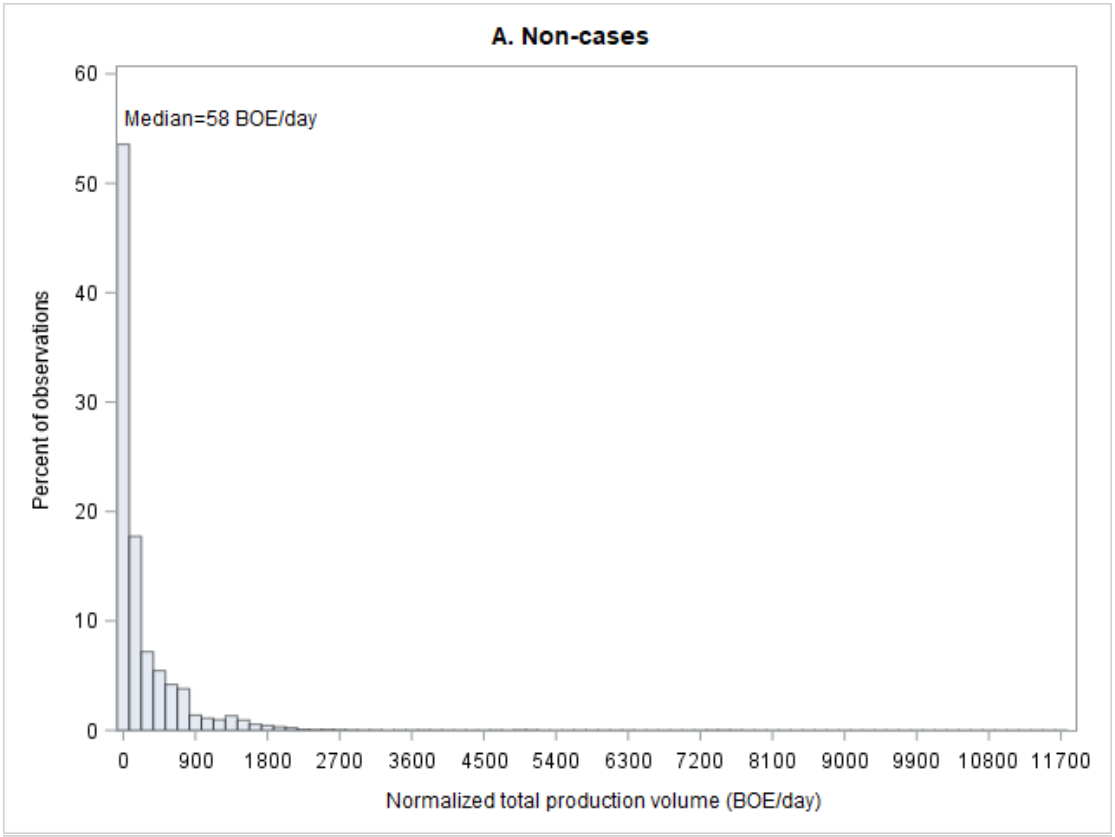


Figure S2. Distribution of total production volume (BOE) per day by non-cases of LBW (A) and cases of LBW (B). The distribution was generated for birth outcome cases and non-cases in order to select a cut-off around the median for each category of exposure to active wells. The distribution of normalized BOE/day was similar across cases of LBW, PTB and SGA. One cut-off was selected for comparability and the value of the cut-off was selected to ensure sufficient overall sample size and number of cases in each exposure group. Figures generated in SAS 9.4 (SAS Institute Inc., Cary, NC).



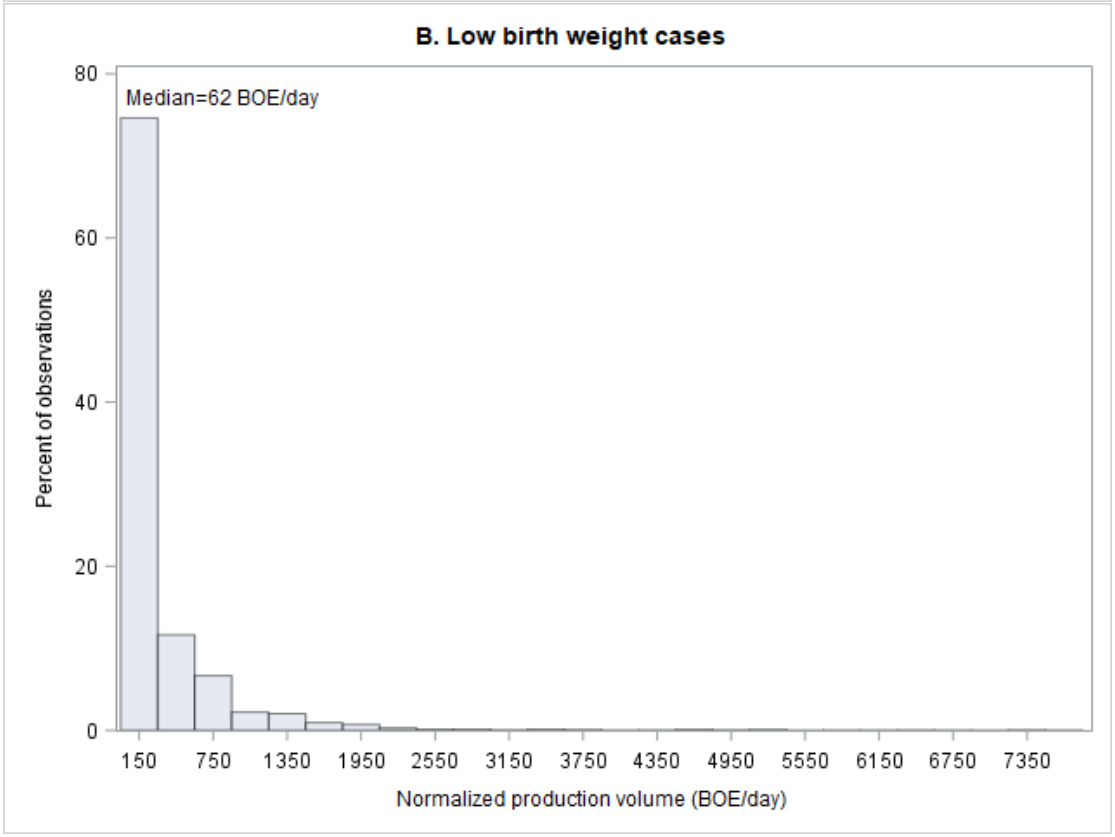


Figure S3. Semi-variogram generated to assess residual spatial dependence. Distances between observations were grouped into 30 distance classes to generate corresponding averages of the semi-variances. The nearly straight line indicates that there is no spatial autocorrelation between the observations. Figure generated in SAS 9.4 (SAS Institute Inc., Cary, NC).

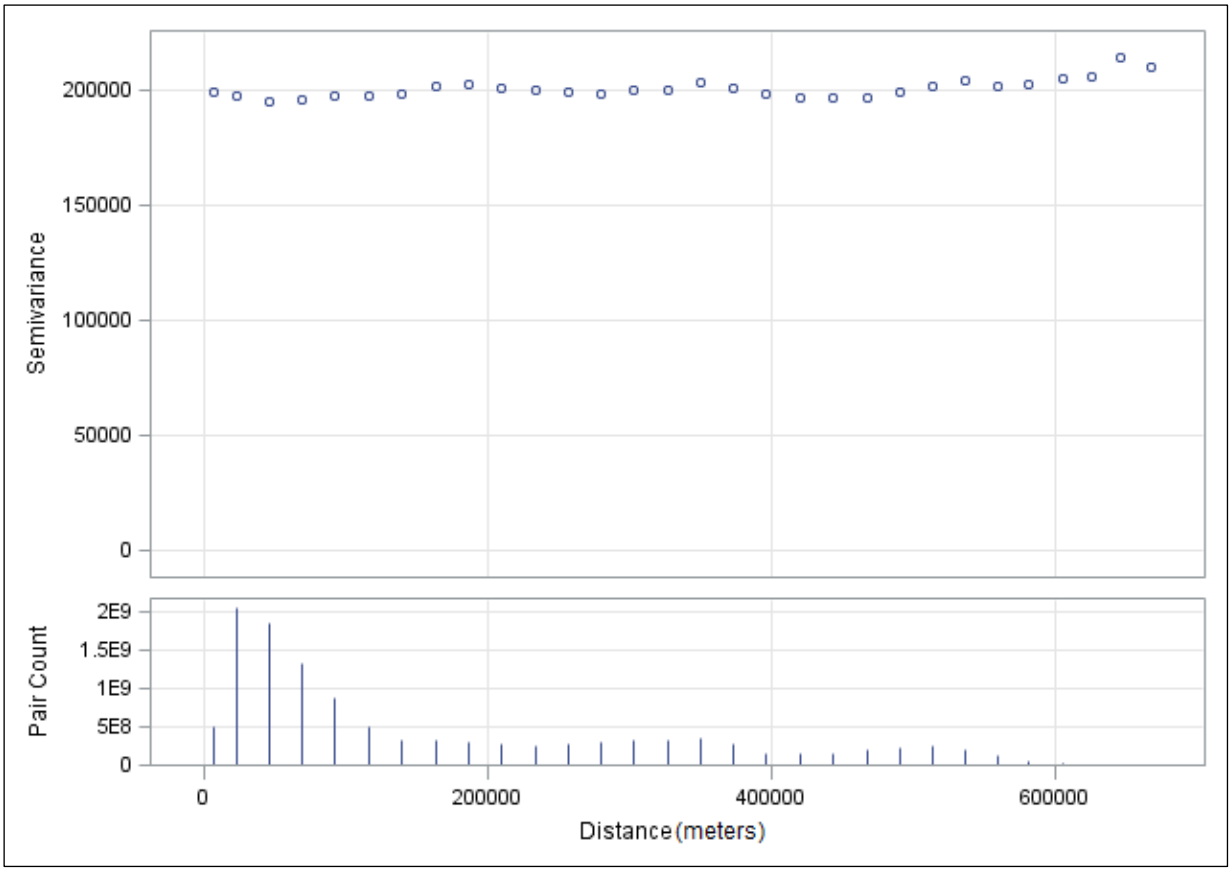
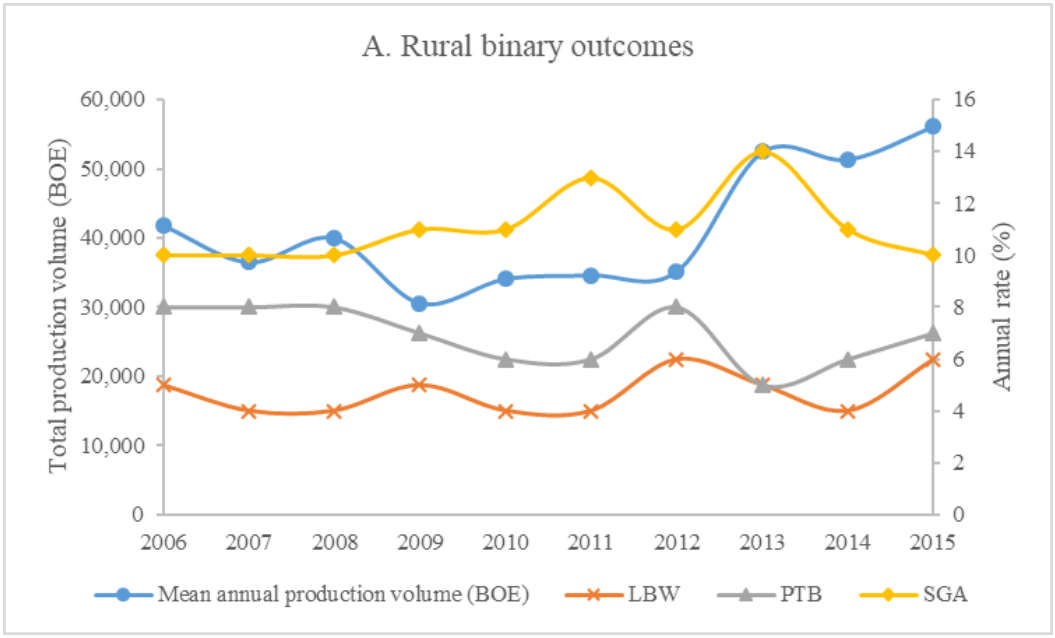
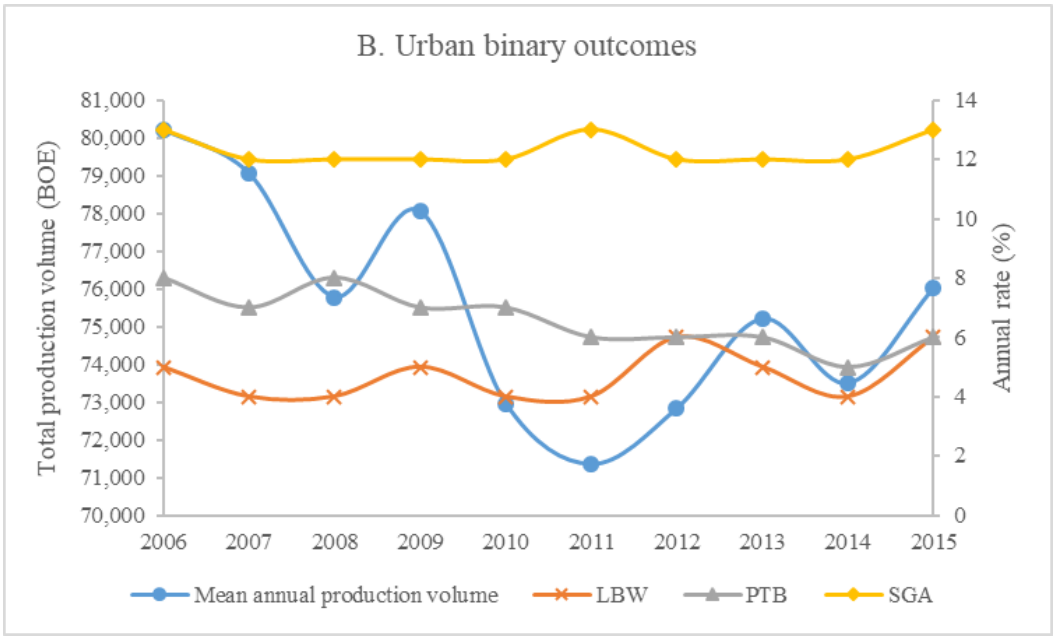
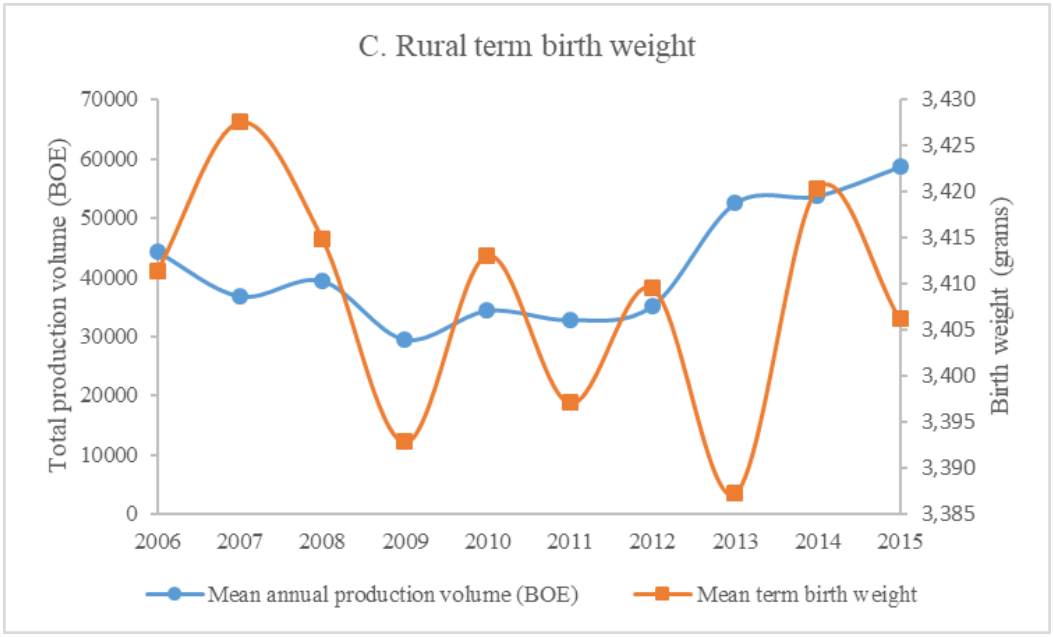


Figure S4. Distribution of the average total production volume (BOE) and birth outcomes by year of birth. Total production volume reflects exposure that occurred during pregnancy, most of which occurred the prior year of birth. The annual rates of LBW, PTB and SGA are plotted for rural (A) and urban (B) areas. The birth weight plots include only term births and the mean term birth weight is plotted for rural (C) and urban (D) areas.






C. Rural term birth weight
Total production volume (BOE)
70000
60000
50000
40000
30000
20000
10000
0
Birth weight (grams)
3,430
3,425
3,420
3,415
3,410
3,405
3,400
3,395
3,390
3,385
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Mean annual production volume (BOE)
Mean term birth weight

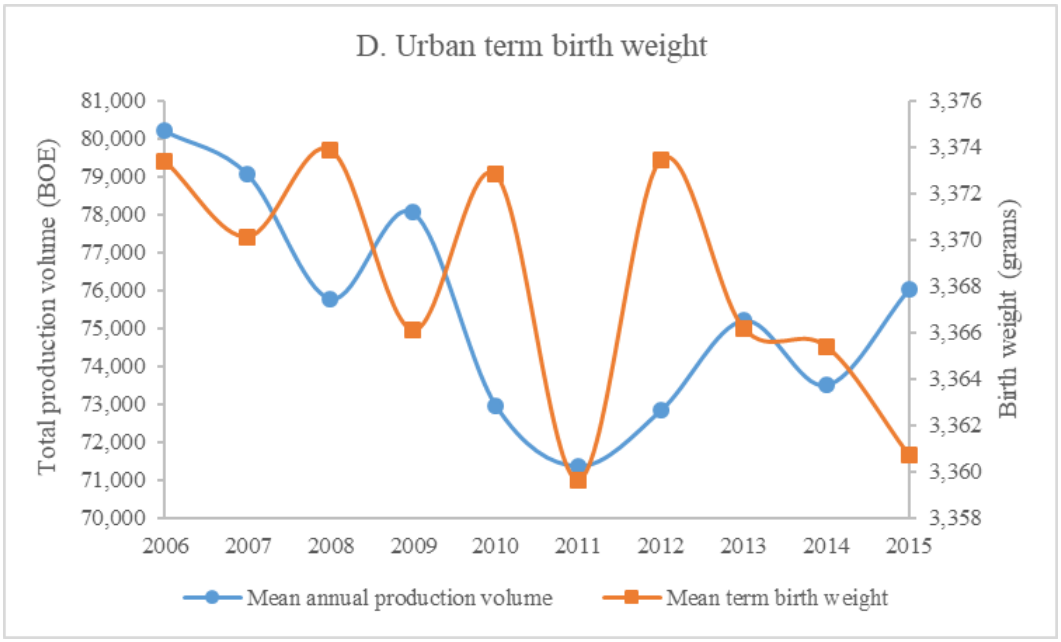

D. Urban term birth weight
Total production volume (BOE)
81,000
80,000
79,000
78,000
77,000
76,000
75,000
74,000
73,000
72,000
71,000
70,000
Birth weight (grams)
3,376
3,374
3,372
3,370
3,368
3,366
3,364
3,362
3,360
3,358
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Mean annual production volume
Mean term birth weight

Table Sl. Adjusted odds ratio for binary birth outcomes associated with exposure to inactive wells by rural/urban status. Data for Figure 3A-3C.

Inactive count categories	No BOE (ref)		1 well			2-5 wells			6+ wells		
	n	Cases (%)	*n*	Cases (%)	aOR (95% CI)	*n*	Cases (%)	aOR (95% CI)	n	Cases (%)	aOR (95% CI)
Low birth weight: Rural[a]											
Entire pregnancy	244,817	11,225 (5)	36,357	1,684 (5)	1.03 (0.97, 1.08)	26,387	1,116 (4)	0.92 (0.86, 0.99)	21,573	920 (4)	0.91 (0.81, 1.01)
Trimester 1	244,817	11,225 (5)	36,347	1,684 (5)	1.03 (0.97, 1.08)	26,371	1,116 (4)	0.92 (0.86, 0.99)	21,599	920 (4)	0.90 (0.81, 1.01)
Trimester 2	244,816	11,225 (5)	36,349	1,684 (5)	1.03 (0.97, 1.08)	26,380	1,115 (4)	0.92 (0.86, 0.99)	21,589	921 (4)	0.91 (0.82, 1.01)
Trimester 3	244,045	10,609 (4)	36,231	1,589 (4)	1.02 (0.97, 1.08)	26,307	1,058 (4)	0.92 (0.85, 0.99)	21,540	864 (4)	0.91 (0.82, 1.02)
Low birth weight: Urban[a]											
Entire pregnancy	1,630,956	84,068 (5)	380,234	19,391 (5)	0.98 (0.97, 1.00)	319,349	16,515 (5)	1.00 (0.98, 1.02)	258,416	13,181 (5)	0.96 (0.94, 0.99)
Trimester 1	1,630,889	84,063 (5)	380,265	19,391 (5)	0.98 (0.97, 1.00)	319,300	16,516 (5)	1.00 (0.98, 1.02)	258,501	13,185 (5)	0.96 (0.94, 0.99)
Trimester 2	1,630,924	84,067 (5)	380,233	19,391 (5)	0.98 (0.97, 1.00)	319,317	16,512 (5)	1.00 (0.98, 1.02)	258,481	13,185 (5)	0.96 (0.94, 0.99)
Trimester 3	1,625,253	79,173 (5)	378,963	18,278 (5)	0.98 (0.97, 1.00)	318,249	15,582 (5)	1.00 (0.98, 1.02)	257,713	12,483 (5)	0.97 (0.94, 1.00)
Preterm birth: Rural[a]											
Entire pregnancy	244,817	16,322 (7)	36,357	2,301 (6)	0.98 (0.93, 1.03)	26,387	1,569 (6)	0.95 (0.88, 1.02)	21,573	1,370 (6)	1.01 (0.89, 1.14)
Trimester 1	244,817	16,322 (7)	36,347	2,301 (6)	0.98 (0.93, 1.03)	26,371	1,567 (6)	0.94 (0.88, 1.02)	21,599	1,372 (6)	1.01 (0.89, 1.14)
Trimester 2	244,816	16,322 (7)	36,349	2,301 (6)	0.98 (0.93, 1.03)	26,380	1,567 (6)	0.94 (0.88, 1.02)	21,589	1,372 (6)	1.00 (0.88, 1.13)
Trimester 3	244,045	15,551 (6)	36,231	2,191 (6)	0.98 (0.93, 1.03)	26307	1,500 (6)	0.94 (0.88, 1.02)	21,540	1,309 (6)	1.02 (0.90, 1.15)
Preterm birth: Urban[a]											
Entire pregnancy	1,630,956	113,646 (7)	380,234	25,375 (7)	0.97 (0.95, 0.99)	319,349	21,838 (7)	1.01 (0.99, 1.03)	258,416	17,039 (7)	0.97 (0.94, 0.99)
Trimester 1	1,630,889	113,635 (7)	380,265	25,383 (7)	0.97 (0.96, 0.99)	319,300	21,835 (7)	1.01 (0.99, 1.03)	258,501	17,045 (7)	0.97 (0.94, 0.99)
Trimester 2	1,630,924	113,644 (7)	380,233	25,376 (7)	0.97 (0.95, 0.99)	319,317	21,835 (7)	1.01 (0.99, 1.03)	258,481	17,043 (7)	0.97 (0.94, 0.99)
Trimester 3	1,625,253	107,975 (7)	378,963	24,117 (6)	0.97 (0.95, 0.99)	318,249	20,787 (7)	1.01 (0.99, 1.03)	257,713	16,242 (6)	0.97 (0.95,1.00)
Small for gestational age: Rural[a]											
Entire pregnancy	244,817	25,536 (10)	36,357	3,702 (10)	0.96 (0.93, 1.00)	26,387	2,726 (10)	0.98 (0.94, 1.03)	21,573	2,247 (10)	0.95 (0.89, 1.02)
Trimester 1	244,817	25,536 (10)	36,347	3,701 (10)	0.96 (0.93, 1.00)	26,371	2,724 (10)	0.98 (0.94, 1.03)	21,599	2,250 (10)	0.96 (0.89, 1.03)
Trimester 2	244,816	25,536 (10)	36,349	3,702 (10)	0.96 (0.93, 1.00)	26,380	2,724 (10)	0.98 (0.93, 1.03)	21,589	2,249 (10)	0.95 (0.89, 1.02)
Trimester 3	244,045	25,501 (10)	36,231	3,699 (10)	0.96 (0.93, 1.00)	26307	2,722 (10)	0.98 (0.94, 1.03)	21,540	2,247 (10)	0.95 (0.89, 1.02)
Small for gestational age: Urban[a]											
Entire pregnancy	1,630,956	189,858 (12)	380,234	45,158 (12)	0.99 (0.98, 1.00)	319,349	37,830 (12)	0.99 (0.98, 1.00)	258,416	30,886 (12)	0.98 (0.96, 1.00)
Trimester 1	1,630,889	189,846 (12)	380,265	45,165 (12)	0.99 (0.98, 1.00)	319,300	37,825 (12)	0.99 (0.98, 1.00)	258,501	30,896 (12)	0.98 (0.96, 1.00)
Trimester 2	1,630,924	189,856 (12)	380,233	45,157 (12)	0.99 (0.98, 1.00)	319,317	37,822 (12)	0.99 (0.98, 1.00)	258,481	30,897 (12)	0.98 (0.96, 1.00)
Trimester 3	1,625,253	189,539 (12)	378,963	45,094 (12)	0.99 (0.98, 1.00)	318,249	37,773 (12)	0.99 (0.98, 1.00)	257,713	30,849 (12)	0.98 (0.96, 1.00)

Note: aOR, adjusted odds ratio, CI, confidence interval.

[a]Logistic regression models adjusted for production volume; child's sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, and ICE for income.

Table S2. Adjusted odds ratio for term birth weight (grams) associated with exposure to inactive wells by rural/urban status. Data for Figure 3D.

Inactive count categories	0 wells (ref)	1 well		2-5 wells		6+ wells	
	n	*n*	aDiff (95% CI)	*n*	aDiff (95% CI)	n	aDiff (95% CI)
Rural[a]							
Entire pregnancy	228,495	34,056	4 (-2, 11)	24,818	-2 (-10, 6)	20,203	-5 (-16, 5)
Trimester 1	228,495	34,046	4 (-2, 11)	24,804	-2 (-10, 6)	20,227	-5 (-16, 5)
Trimester 2	228,494	34,048	4 (-2, 11)	24,813	-2 (-10, 6)	20,217	-5 (-16, 5)
Trimester 3	228,494	34,040	4 (-2, 11)	24,807	-2 (-10, 5)	20,231	-6 (-17, 5)
Urban[a]							
Entire pregnancy	1,517,310	354,859	2 (0, 5)	297,511	4 (1, 6)	241,377	5 (1, 8)
Trimester 1	1,517,254	354,882	2 (0, 5)	297,465	4 (1, 6)	241,456	5 (1, 8)
Trimester 2	1,517,280	354,857	2 (0, 5)	297,482	4 (1, 6)	241,438	5 (1, 8)
Trimester 3	1,517,278	354,846	2 (0, 5)	297,462	4 (1, 6)	241,471	5 (1, 8)

Note: aDiff, adjusted mean difference (grams); CI, confidence interval.

[a]Linear regression models adjusted for production volume; child's gestational age, sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, and ICE for income.

Table S3. Unstratified adjusted odds ratios and mean difference (grams) for adverse birth outcomes associated with exposure to oil and gas production.

Prod volume categories	No BOE (ref)		1-100 BOE/day			GT 100 BOE/day		
	n	Cases (%)	*n*	Cases (%)	EE (95% CI)	n	Cases (%)	EE (95% CI)
Low birth weight[a]								
Entire pregnancy	2,800,901	141,984 (5)	68,642	3,561 (5)	1.05 (1.01, 1.09)	48,546	2,555 (5)	1.00 (0.96, 1.06)
Trimester 1	2,801,853	142,033 (5)	67,776	3,513 (5)	1.05 (1.00, 1.09)	48,460	2,554 (5)	1.01 (0.96, 1.06)
Trimester 2	2,801,831	142,027 (5)	63,706	3,317 (5)	1.05 (1.01, 1.10)	52,552	2,756 (5)	1.01 (0.96, 1.05)
Trimester 3	2,793,270	133,973 (5)	72,835	3,657 (6)	1.06 (1.02, 1.11)	42,196	2,006 (4)	0.94 (0.89, 1.00)
Preterm birth[a]								
Entire pregnancy	2,800,901	191,536 (7)	68,642	4,738 (7)	1.01 (0.97, 1.06)	48,546	3,186 (7)	0.95 (0.91, 1.00)
Trimester 1	2,801,853	191,592 (7)	67,776	4,692 (7)	1.02 (0.98, 1.06)	48,460	3,176 (7)	0.95 (0.91, 1.00)
Trimester 2	2,801,831	191,578 (7)	63,706	4,450 (7)	1.03 (0.99, 1.07)	52,552	3,432 (7)	0.95 (0.90, 1.00)
Trimester 3	2,793,270	182,284 (7)	72,835	5,011 (7)	1.06 (1.02, 1.10)	42,196	2,377 (6)	0.83 (0.78, 0.88)
Small for gestational age[a]								
Entire pregnancy	2,800,901	323,688 (12)	68,642	8,305 (12)	1.04 (1.00, 1.07)	48,546	5,950 (12)	1.05 (1.01, 1.08)
Trimester 1	2,801,853	323,824 (12)	67,776	8,183 (12)	1.03 (1.00, 1.07)	48,460	5,936 (12)	1.05 (1.01, 1.08)
Trimester 2	2,801,831	323,806 (12)	63,706	7,723 (12)	1.04 (1.00, 1.07)	52,552	6,414 (12)	1.04 (1.01, 1.07)
Trimester 3	2,793,270	323,405 (12)	72,835	8,806 (12)	1.04 (1.00, 1.07)	42,196	5,213 (12)	1.05 (1.02, 1.09)
Term birth weight[b]								
Entire pregnancy	2,609,365	--	63,904	--	-3 (-8, 2)	45,360	--	-5 (-10, 1)
Trimester 1	2,610,261	--	63,084	--	-3 (-8, 2)	45,284	--	-4 (-10, 2)
Trimester 2	2,610,253	--	59,256	--	-3 (-8, 3)	49,120	--	-4 (-10, 1)
Trimester 3	2,610,986	--	67,824	--	-3 (-8, 2)	39,819	--	-4 (-10, 3)

Note: EE, effect estimate; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than.

[a]Logistic regression models (odds ratio) adjusted for inactive well count; child's sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; urban indicator, air basin, NO_2 concentration, and ICE for income.

[b]Linear regression model (mean difference, grams) also adjusted for gestational age.

Table S4. Adjusted odds ratios for low birth weight associated with oil and gas production volume by urban/rural status. Data for Figure 4A. Effect modification p-values were derived from two-sample z-tests using strata-specific estimates and variances; significance at α=0.05.

Prod volume categories	No BOE (ref)		1-100 BOE/day				GT 100 BOE/day			
	n	Cases (%)	*n*	Cases (%)	aOR (95% CI)	EM p-value	n	Cases (%)	aOR (95% CI)	EM p-value
Rural[a]										
Entire pregnancy	318,488	14,451 (5)	8,957	400 (4)	1.11 (0.97, 1.27)	0.81	1,689	94 (6)	1.40 (1.14, 1.71)	0.01
Trimester 1	318,629	14,457 (5)	8,809	394 (4)	1.12 (0.98, 1.28)	0.67	1,696	94 (6)	1.39 (1.11, 1.75)	0.002
Trimester 2	318,675	14,461 (5)	8,258	367 (4)	1.10 (0.96, 1.26)	1.00	2,201	117 (5)	1.35 (1.13, 1.61)	0.002
Trimester 3	317,913	13,684 (4)	8,790	359 (4)	1.07 (0.93, 1.23)	1.00	1,420	77 (5)	1.38 (1.11, 1.72)	0.01
Urban[a]										
Entire pregnancy	2,482,413	127,533 (5)	59,685	3,161 (5)	1.04 (1.00, 1.09)	--	46,857	2,461 (5)	0.99 (0.95, 1.04)	--
Trimester 1	2,483,224	127,576 (5)	58,967	3,119 (5)	1.04 (0.99, 1.09)	--	46,764	2,460 (5)	1.00 (0.95, 1.04)	--
Trimester 2	2,483,156	127,566 (5)	55,448	2,950 (5)	1.05 (1.00, 1.10)	--	50,351	2,639 (5)	0.99 (0.95, 1.04)	--
Trimester 3	2,475,357	120,289 (5)	64,045	3,298 (5)	1.06 (1.02, 1.11)	--	40,776	1,929 (5)	0.93 (0.88, 0.98)	--

Note: aOR, adjusted odds ratio; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than; EM, effect modification.

[a]Logistic regression models adjusted for inactive well count; child's sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, and ICE for income.

Table S5. Adjusted odds ratios for preterm birth associated with oil and gas production volume by urban/rural status. Data for Figure 4B. Effect modification p-values were derived from two-sample z-tests using strata-specific estimates and variances; significance at α=0.05.

Prod volume categories	No BOE (ref)		1-100 BOE/day				GT 100 BOE/day			
	n	Cases (%)	*n*	Cases (%)	aOR (95% CI)	EM p-value	n	Cases (%)	aOR (95% CI)	EM p-value
Rural[a]										
Entire pregnancy	318,488	20,845 (7)	8,957	618 (7)	1.03 (0.91, 1.18)	1.00	1,689	99 (6)	0.97 (0.78, 1.21)	1.00
Trimester 1	318,629	20,857 (7)	8,809	604 (7)	1.02 (0.90, 1.16)	1.00	1,696	101 (6)	1.00 (0.80, 1.24)	1.00
Trimester 2	318,675	20,850 (7)	8,258	582 (7)	1.06 (0.94, 1.21)	1.00	2,201	130 (6)	0.98 (0.82, 1.18)	1.00
Trimester 3	317,913	19,899 (6)	8,790	575 (7)	1.03 (0.90, 1.17)	1.00	1,420	77 (5)	0.92 (0.71, 1.19)	0.84
Urban[a]										
Entire pregnancy	2,482,413	170,691 (7)	59,685	4,120 (7)	1.01 (0.97, 1.06)	--	46,857	3,087 (7)	0.95 (0.90, 1.00)	--
Trimester 1	2,483,224	170,735 (7)	58,967	4,088 (7)	1.01 (0.97, 1.06)	--	46,764	3,075 (7)	0.95 (0.91, 1.00)	--
Trimester 2	2,483,156	170,728 (7)	55,448	3,868 (7)	1.02 (0.98, 1.07)	--	50,351	3,302 (7)	0.95 (0.90, 1.00)	--
Trimester 3	2,475,357	162,385 (7)	64,045	4,436 (7)	1.06 (1.02, 1.11)	--	40,776	2,300 (6)	0.82 (0.77, 0.88)	--

Note: aOR, adjusted odds ratio; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than; EM, effect modification.

[a]Logistic regression models adjusted for inactive well count; child's sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, and ICE for income.

Table S6. Adjusted odds ratios for small for gestational age associated with oil and gas production volume by urban/rural status. Data for Figure 4C. Effect modification p-values were derived from two-sample z-tests using strata-specific estimates and variances; significance at α=0.05.

Prod volume categories	No BOE (ref)		1-100 BOE/day				GT 100 BOE/day			
	n	Cases (%)	*n*	Cases (%)	aOR (95% CI)	EM p-value	n	Cases (%)	aOR (95% CI)	EM p-value
Rural[a]										
Entire pregnancy	318,488	33,034 (10)	8,957	966 (11)	1.07 (0.97, 1.19)	0.99	1,689	211 (13)	1.22 (1.02, 1.45)	0.14
Trimester 1	318,629	33,056 (10)	8,809	937 (11)	1.05 (0.95, 1.16)	1.00	1,696	218 (13)	1.25 (1.04, 1.50)	0.07
Trimester 2	318,675	33,058 (10)	8,258	889 (11)	1.07 (0.96, 1.19)	1.00	2,201	264 (12)	1.17 (1.02, 1.35)	0.20
Trimester 3	317,913	33,038 (10)	8,790	948 (11)	1.08 (0.97, 1.19)	0.90	1,420	183 (13)	1.24 (1.02, 1.50)	0.14
Urban[a]										
Entire pregnancy	2,482,413	290,654 (12)	59,685	7,339 (12)	1.03 (1.00, 1.07)	--	46,857	5,739 (12)	1.04 (1.01, 1.07)	--
Trimester 1	2,483,224	290,768 (12)	58,967	7,246 (12)	1.03 (1.00, 1.07)	--	46,764	5,718 (12)	1.04 (1.00, 1.07)	--
Trimester 2	2,483,156	290,748 (12)	55,448	6,834 (12)	1.03 (1.00, 1.07)	--	50,351	6,150 (12)	1.04 (1.00, 1.07)	--
Trimester 3	2,475,357	290,367 (12)	64,045	7,858 (12)	1.03 (1.00, 1.07)	--	40,776	5,030 (12)	1.04 (1.01, 1.08)	--

Note: aOR, adjusted odds ratio; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than; EM, effect modification.

[a]Logistic regression models adjusted for inactive well count; child's sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, and ICE for income.

Table S7. Adjusted mean difference of term birth weight (grams) associated with oil and gas production volume by urban/rural status. Data for Figure 4D. Effect modification p-values were derived from two-sample z-tests using strata-specific estimates and variances; significance at α=0.05.

Prod volume categories	No BOE (ref)	1-100 BOE/day			GT 100 BOE/day		
	n	n	aDiff (95% CI)	EM p-value	n	aDiff (95% CI)	EM p-value
Rural[a]							
Entire pregnancy	297,643	8,339	3 (-11, 18)	0.62	1,590	-36 (-54, -17)	0.001
Trimester 1	297,772	8,205	4 (-10, 18)	0.47	1,595	-39 (-59, -19)	0.0003
Trimester 2	297,825	7,676	3 (-12, 18)	0.71	2,071	-27 (-45, -8)	0.01
Trimester 3	298,014	8,215	4 (-11, 20)	0.41	1,343	-30 (-48, -12)	0.001
Urban[a]							
Entire pregnancy	2,311,722	55,565	-5 (-10, 1)	--	43,770	1 (-5, 8)	--
Trimester 1	2,312,489	54,879	-5 (-11, 1)	--	43,689	2 (-4, 9)	--
Trimester 2	2,312,428	51,580	-5 (-11, 1)	--	47,049	2 (-4, 8)	--
Trimester 3	2,312,972	59,609	-6 (-12, 0)	--	38,476	5 (-2, 12)	--

Note: aDiff, adjusted mean difference (grams); CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than; EM, effect modification.

[a]Linear regression models adjusted for inactive well count; child's gestational age, sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, and ICE for income.

Table S8. Rural adjusted odds ratios and mean difference (grams) for adverse birth outcomes associated with exposure to oil and gas production during the entire pregnancy by maternal race/ethnicity. Effect modification p-values were derived from two-sample z-tests using strata-specific estimates and variances; significance at α=0.05. Non-Hispanic Whites were used as the reference in z-tests. EM p-values were not reported for categories with no observations.

Prod volume categories	No BOE (ref)		1-100 BOE/day				GT 100 BOE/day			
	n	Cases (%)	*n*	Cases (%)	EE (95% CI)	EM p-value	n	Cases (%)	EE (95% CI)	EM p-value
Low birth weight[a]										
Asian/Pacific Islander	28,530	1,689 (6)	403	17 (4)	1.07 (0.59, 1.95)	1.00	326	23 (7)	2.04 (1.21, 3.43)	0.29
Black	6,313	494 (8)	81	4 (5)	0.65 (0.22, 1.96)	1.00	13	1 (8)	1.40 (0.47, 4.16)	1.00
Hispanic	164,739	7,735 (5)	5,828	283 (5)	1.16 (0.99, 1.37)	1.00	655	36 (6)	1.31 (1.02, 1.69)	1.00
Other	8,262	407 (5)	119	7 (6)	0.96 (0.47, 1.96)	1.00	27	0 (0)	--	--
White (ref)	110,644	4,126 (4)	2,526	89 (4)	1.04 (0.79, 1.37)	--	668	34 (5)	1.37 (0.89, 2.12)	--
Preterm birth[a]										
Asian/Pacific Islander	28,530	1,831 (6)	403	23 (6)	1.01 (0.56, 1.81)	1.00	326	17 (5)	1.06 (0.74, 1.52)	1.00
Black	6,313	590 (9)	81	2 (2)	--	0.56	13	0 (0)	--	--
Hispanic	164,739	11,882 (7)	5,828	458 (8)	1.14 (0.97, 1.33)	0.54	655	42 (6)	0.95 (0.69, 1.31)	1.00
Other	8,262	587 (7)	119	7 (6)	0.73 (0.21, 1.73)	1.00	27	1 (4)	0.53 (0.09, 3.16)	1.00
White (ref)	110,644	5,955 (5)	2,526	128 (5)	0.89 (0.70, 1.14)	--	668	39 (6)	0.94 (0.68, 1.31)	--
Small for gestational age[a]										
Asian/Pacific Islander	28,530	4,458 (16)	403	71 (18)	1.30 (0.90, 1.87)	1.00	326	51 (16)	1.09 (0.84, 1.42)	0.51
Black	6,313	978 (15)	81	12 (15)	0.81 (0.42, 1.57)	1.00	13	1 (8)	0.38 (0.12, 1.24)	1.00
Hispanic	164,739	17,307 (11)	5,828	646 (11)	1.08 (0.97, 1.22)	1.00	655	79 (12)	1.21 (0.91, 1.61)	1.00
Other	8,262	899 (11)	119	14 (12)	0.96 (0.50, 1.83)	1.00	27	6 (22)	2.03 (0.86, 4.58)	1.00
White (ref)	110,644	9,392 (9)	2,526	223 (9)	1.03 (0.84, 1.27)	--	668	74 (11)	1.24 (1.00, 1.56)	--
Term birth weight[b]										
Asian/Pacific Islander	26,699	--	380	--	-13 (-67, 42)	1.00	309	--	-23 (-62, 15)	1.00
Black	5,723	--	79	--	6 (-136, 148)	1.00	13	--	-115 (-257, 27)	1.00
Hispanic	152,857	--	5,370	--	-6 (-22, 10)	0.11	613	--	-23 (-53, 7)	1.00
Other	7,675	--	112	--	82 (-28, 192)	1.00	26	--	-147 (-320, 26)	1.00
White (ref)	104,689	--	2,398	--	23 (-4, 50)	--	629	--	-32 (-65, 0)	--

Note: EE, effect estimate; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than; EM, effect modification.

[a]Logistic regression models (odds ratio) adjusted for inactive well count; child's sex, birth month and birth year; maternal education, age, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, and ICE for income.

[b]Linear regression model (mean difference, grams) also adjusted for gestational age.

Table S9. Urban adjusted odds ratios and mean difference (grams) for adverse birth outcomes associated with exposure to oil and gas production during the entire pregnancy by maternal race/ethnicity.

Prod volume categories	No BOE (ref)		1-100 BOE/day			GT 100 BOE/day		
	n	Cases (%)	*n*	Cases (%)	EE (95% CI)	n	Cases (%)	EE (95% CI)
Low birth weight[a]								
Asian/Pacific Islander	305,228	17,621 (6)	7,253	389 (5)	1.06 (0.94, 1.19)	6,182	376 (6)	1.10 (0.98, 1.23)
Black	136,701	13,034 (10)	3,655	370 (10)	1.13 (1.00, 1.29)	4,299	391 (9)	1.04 (0.93, 1.17)
Hispanic	1,417,139	71,208 (5)	34,986	1,791 (5)	1.01 (0.95, 1.07)	22,459	1,172 (5)	0.98 (0.92, 1.05)
Other	54,716	3,119 (6)	1,093	65 (6)	1.20 (0.87, 1.65)	1,209	70 (6)	1.18 (0.87, 1.61)
White	568,629	22,551 (4)	12,698	546 (4)	1.06 (0.96, 1.18)	12,708	452 (4)	0.87 (0.78, 0.98)
Preterm birth[a]								
Asian/Pacific Islander	305,228	18,550 (6)	7,253	388 (5)	1.05 (0.92, 1.20)	6,182	354 (6)	1.00 (0.87, 1.15)
Black	136,701	13,956 (10)	3,655	408 (11)	1.11 (0.97, 1.28)	4,299	398 (9)	0.91 (0.80, 1.04)
Hispanic	1,417,139	103,664 (7)	34,986	2,540 (7)	0.99 (0.94, 1.05)	22,459	1,630 (7)	0.93 (0.88, 0.99)
Other	54,716	3,854 (7)	1,093	88 (8)	1.15 (0.88, 1.50)	1,209	80 (7)	0.94 (0.70, 1.25)
White	568,629	30,667 (5)	12,698	696 (5)	0.99 (0.90, 1.10)	12,708	625 (5)	0.93 (0.84, 1.03)
Small for gestational age[a]								
Asian/Pacific Islander	305,228	48,463 (16)	7,253	1,185 (16)	1.04 (0.95, 1.13)	6,182	1,045 (17)	1.11 (1.03, 1.21)
Black	136,701	24,563 (18)	3,655	702 (19)	1.14 (1.05, 1.25)	4,299	770 (18)	1.11 (1.00, 1.22)
Hispanic	1,417,139	160,491 (11)	34,986	4,149 (12)	1.01 (0.97, 1.06)	22,459	2,558 (11)	0.99 (0.94, 1.04)
Other	54,716	6,581 (12)	1,093	148 (14)	1.31 (1.07, 1.59)	1,209	147 (12)	1.17 (0.95, 1.15)
White	568,629	50,556 (9)	12,698	1,155 (9)	0.98 (0.91, 1.05)	12,708	1,219 (10)	1.01 (0.94, 1.09)
Term birth weight[b]								
Asian/Pacific Islander	286,678	--	6,865	--	-3 (-20, 14)	5,828	--	-16 (-30, -1)
Black	122,745	--	3,247	--	-35 (-53, -18)	3,901	--	-4 (-22, 14)
Hispanic	1,313,475	--	32,446	--	0 (-8, 7)	20,829	--	10 (1, 18)
Other	50,862	--	1,005	--	-23 (-55, 9)	1,129	--	-5 (-39, 29)
White	537,962	--	12,002	--	-2 (-12, 9)	12,083	--	3 (-8, 15)

Note: EE, effect estimate; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than.

[a]Logistic regression models (odds ratio) adjusted for inactive well count; child's sex, birth month and birth year; maternal education, age, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, and ICE for income.

[b]Linear regression model (mean difference) also adjusted for gestational age.

Table S10. Rural adjusted odds ratios and mean difference (grams) for adverse birth outcomes associated with exposure to oil and gas production during the entire pregnancy by air basin. Effect modification p-values were derived from two-sample z-tests using strata-specific estimates and variances; significance at α=0.05. Sacramento Valley was used the reference for all z-tests.

Prod volume categories	No BOE (ref)		1-100 BOE/day				GT 100 BOE/day			
	n	Cases (%)	*n*	Cases (%)	EE (95% CI)	EM p-value	n	Cases (%)	EE (95% CI)	EM p-value
Low birth weight[a]										
Sacramento Valley (ref)	51,150	2,132 (4)	1,036	38 (4)	0.84 (0.52, 1.35)	--	237	14 (6)	1.37 (0.82, 2.26)	--
San Joaquin Valley	157,748	7,509 (5)	4,501	214 (5)	1.14 (0.95, 1.37)	1.00	571	37 (6)	1.48 (1.05, 2.07)	1.00
South Central Coast	36,860	1,552 (4)	2,820	120 (4)	1.05 (0.84, 1.30)	1.00	300	14 (5)	1.32 (0.90, 1.93)	1.00
South Coast	72,730	3,258 (4)	600	28 (5)	1.38 (0.86, 2.23)	0.97	581	29 (5)	1.41 (1.14, 1.74)	1.00
Preterm birth[a]										
Sacramento Valley (ref)	51,150	2,999 (6)	1,036	56 (5)	0.68 (0.47, 0.99)	--	237	16 (7)	0.86 (0.56, 1.32)	--
San Joaquin Valley	157,748	11,575 (7)	4,501	344 (8)	1.02 (0.86, 1.21)	0.45	571	48 (8)	1.05 (0.82, 1.33)	1.00
South Central Coast	36,860	2,052 (6)	2,820	183 (7)	1.09 (0.88, 1.35)	0.17	300	8 (3)	0.54 (0.33, 0.87)	0.67
South Coast	72,730	4,219 (6)	600	35 (6)	1.21 (0.91, 1.61)	0.14	581	27 (5)	0.98 (0.75, 1.30)	1.00
Small for gestational age[a]										
Sacramento Valley (ref)	51,150	4,769 (9)	1,036	89 (9)	1.03 (0.76, 1.40)	--	237	16 (7)	0.80 (0.54, 1.18)	--
San Joaquin Valley	157,748	16,910 (11)	4,501	498 (11)	1.09 (0.94, 1.27)	1.00	571	87 (15)	1.53 (1.19, 1.97)	0.05
South Central Coast	36,860	3,539 (10)	2,820	296 (11)	1.03 (0.90, 1.20)	1.00	300	38 (13)	1.38 (1.22, 1.57)	0.11
South Coast	72,730	7,816 (11)	600	83 (14)	1.26 (1.03, 1.53)	1.00	581	70 (12)	1.00 (0.81, 1.25)	1.00
Term birth weight[b]										
Sacramento Valley (ref)	48,151	--	980	--	18 (-27, 64)	--	221	--	-48 (-100, 4)	--
San Joaquin Valley	146,173	--	4,157	--	-1 (-23, 21)	1.00	523	--	-38 (-77, 1)	1.00
South Central Coast	34,808	--	2,637	--	2 (-22, 25)	1.00	292	--	-42 (-74, -10)	1.00
South Coast	68,511	--	565	--	-7 (-30, 17)	1.00	554	--	-31 (-48, -14)	1.00

Note: EE, effect estimate; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than; EM, effect modification.

[a]Logistic regression models (odds ratio) adjusted for inactive well count; child's sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; NO_2 concentration and ICE for income.

[b]Linear regression model (mean difference, grams) also adjusted for gestational age.

Table S11. Urban adjusted odds ratios and mean difference (grams) for adverse birth outcomes associated with exposure to oil and gas production during the entire pregnancy by air basin.

Prod volume categories	No BOE (ref)		1-100 BOE/day			GT 100 BOE/day		
	n	Cases (%)	*n*	Cases (%)	EE (95% CI)	n	Cases (%)	EE (95% CI)
Low birth weight[a]								
Sacramento Valley	238,174	11,524 (5)	0	0 (0)	--	0	0 (0)	--
San Joaquin Valley	377,626	20,833 (6)	9,717	511 (5)	1.02 (0.91, 1.13)	1,517	76 (5)	0.95 (0.78, 1.16)
South Central Coast	131,912	5,886 (4)	1,076	37 (3)	0.70 (0.54, 0.93)	288	15 (5)	1.26 (0.96, 1.65)
South Coast	1,734,701	89,290 (5)	48,892	2,613 (5)	1.05 (1.00, 1.11)	45,052	2,370 (5)	1.00 (0.95, 1.05)
Preterm birth[a]								
Sacramento Valley	238,174	14,318 (6)	0	0 (0)	--	0	0 (0)	--
San Joaquin Valley	377,626	30,907 (8)	9,717	803 (8)	0.99 (0.90, 1.10)	1,517	129 (9)	0.98 (0.84, 1.14)
South Central Coast	131,912	7,730 (6)	1,076	64 (6)	0.86 (0.64, 1.17)	288	23 (8)	1.46 (1.17, 1.82)
South Coast	1,734,701	117,736 (7)	48,892	3,253 (7)	1.01 (0.96, 1.06)	45,052	2,935 (7)	0.97 (0.92, 1.02)
Small for gestational age[a]								
Sacramento Valley	238,174	24,960 (10)	0	0 (0)	--	0	0 (0)	--
San Joaquin Valley	377,626	44,604 (12)	9,717	1,131 (12)	1.00 (0.90, 1.10)	1,517	158 (10)	0.92 (0.80, 1.05)
South Central Coast	131,912	13,798 (10)	1,076	120 (11)	1.06 (0.90, 1.25)	288	34 (12)	1.20 (0.85, 1.71)
South Coast	1,734,701	207,292 (12)	48,892	6,088 (12)	1.04 (1.00, 1.08)	45,052	5,547 (12)	1.04 (1.01, 1.080
Term birth weight[b]								
Sacramento Valley	223,856	--	0	--	--	0	--	--
San Joaquin Valley	346,719	--	8,914	--	2 (-10, 14)	1,388	--	2 (-16, 20)
South Central Coast	124,182	--	1,012	--	4 (-30, 37)	265	--	-52 (-95, -8)
South Coast	1,616,965	--	45,639	--	-6 (-13, 1)	42,117	--	1 (-5, 8)

Note: EE, effect estimate; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than.

[a]Logistic regression models (odds ratio) adjusted for inactive well count; child's sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; NO_2 concentration and ICE for income.

[b]Linear regression model (mean difference, grams) also adjusted for gestational age.

Table S12. Adjusted odds ratios and mean difference (grams) for adverse birth outcomes associated with exposure to oil and gas production during the entire pregnancy by urban/rural status for sensitivity analysis models including maternal pre-pregnancy BMI and smoking during pregnancy (2007-2015). BMI and smoking were not available for 2006 births. Effect estimates did not change by >10% compared to main models. Main models excluded these two covariates in order to maximize sample size.

Prod volume categories	No BOE (ref)		1-100 BOE/day			GT 100 BOE/day		
	n	Cases (%)	*n*	Cases (%)	EE (95% CI)	n	Cases (%)	EE (95% CI)
Low birth weight[a]								
Rural	283,881	12,911 (5)	7,879	357 (5)	1.16 (1.00, 1.36)	1,477	81 (5)	1.32 (1.10, 1.59)
Urban	2,179,247	111,604 (5)	51,676	2,747 (5)	1.04 (0.99, 1.10)	40,147	2,062 (5)	0.96 (0.91, 1.01)
Preterm birth[a]								
Rural	283,881	18,236 (6)	7,879	521 (7)	1.05 (0.91, 1.20)	1,477	85 (6)	0.96 (0.77, 1.21)
Urban	2,179,247	146,242 (7)	51,676	3,439 (7)	1.01 (0.97, 1.06)	40,147	2,535 (6)	0.95 (0.90, 1.00)
Small for gestational age[a]								
Rural	283,881	29,451 (10)	7,879	862 (11)	1.11 (0.99, 1.24)	1,477	190 (13)	1.17 (0.97, 1.42)
Urban	2,179,247	254,729 (12)	51,676	6,361 (12)	1.05 (1.01, 1.09)	40,147	4,828 (12)	1.03 (0.99, 1.06)
Term birth weight[b]								
Rural	265,645	--	7,358	--	-2 (-17, 12)	1,392	--	-31 (-51, -11)
Urban	2,033,005	--	48,237	--	-5 (-11, 2)	37,612	--	3 (-3, 9)

Note: EE, effect estimate; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than.

[a]Logistic regression models (odds ratio) adjusted for inactive well count; child's sex, birth month and birth year; maternal BMI, smoking, education, age, race/ethnicity, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, and ICE for income.

[b]Linear regression model (mean difference) also adjusted for gestational age.

Table S13. Adjusted odds ratios and mean difference (grams) for adverse birth outcomes associated with exposure to oil and gas production during the entire pregnancy by urban/rural status for sensitivity analysis models including an indicator for exposure to TRI facilities within 1 km. The variable was missing for 79,371 observations (3%). Effect estimates did not change by >10%, compared to main models.

Prod volume categories	No BOE (ref)		1-100 BOE/day			GT 100 BOE/day		
	n	Cases (%)	*n*	Cases (%)	EE (95% CI)	n	Cases (%)	EE (95% CI)
Low birth weight[a]								
Rural	318,488	14,451 (5)	8,957	400 (4)	1.11 (0.97, 1.28)	1,689	94 (6)	1.40 (1.14, 1.71)
Urban	2,482,413	127,533 (5)	59,685	3,161 (5)	1.04 (1.00, 1.09)	46,857	2,461 (5)	0.99 (0.95, 1.04)
Preterm birth[a]								
Rural	318,488	20,845 (7)	8,957	618 (7)	1.03 (0.91, 1.17)	1,689	99 (6)	0.97 (0.78, 1.21)
Urban	2,482,413	170,691 (7)	59,685	4,120 (7)	1.01 (0.97, 1.06)	46,857	3,087 (7)	0.95 (0.90, 1.00)
Small for gestational age[a]								
Rural	318,488	33,034 (10)	8,957	966 (11)	1.08 (0.97, 1.19)	1,689	211 (12)	1.22 (1.02, 1.45)
Urban	2,482,413	290,654 (12)	59,685	7,339 (12)	1.03 (1.00, 1.07)	46,857	5,739 (12)	1.04 (1.01, 1.07)
Term birth weight[b]								
Rural	297,643	--	8,339	--	3 (-11, 18)	1,590	--	-36 (-54, -17)
Urban	2,311,722	--	55,565	--	-5 (-10, 1)	43,770	--	1 (-5, 8)

Note: EE, effect estimate; CI, confidence interval; BOE, barrel of oil equivalents of oil and gas; GT, greater than.

[a]Logistic regression models (odds ratio) adjusted for inactive well count; child's sex, birth month and birth year; maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity; air basin, NO_2 concentration, ICE for income and TRI facilities indicator.

[b]Linear regression model (mean difference) also adjusted for gestational age.