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Timing of Prenatal Smoking Cessation or Reduction and Infant Birth Weight: Evidence from the United Kingdom Millennium Cohort Study

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Abstract:

Smoking during pregnancy is a key contributor to poor infant health. Our study presents a dynamic relationship between the timing of prenatal smoking cessation or reduction and infant birth weight. Using a large representative dataset of a birth cohort in the United Kingdom, we apply regression analysis to examine the influences of cessation in smoking or reduction in smoking intensity at different months or trimesters on infant birth weight. For robustness checks, we use a rich set of additional covariates, a series of variable selection procedures, alternative birth outcome measures, and stratified samples. We find robust evidence that mothers who quit smoking by the third month of pregnancy or the end of the first trimester have infants of the same weight as those infants of nonsmokers. However, we find smoking cessation in the fourth month or any time beyond is associated with substantially lower infant birth weights. Two-thirds of the total adverse smoking impact on infant birth weight occurs in the second trimester. Our study also shows mothers who smoke throughout pregnancy but cut smoking intensity by the third month in pregnancy deliver infants of the same weight as those infants born to persistent light smokers. Our research suggests the efficacy of prenatal smoking cessation services can be significantly improved, if health professionals can encourage more pregnant women to quit smoking or reduce smoking intensity timely by the end of the first trimester.

Keywords:

Prenatal smoking • Timing of smoking cessation • Timing of smoking reduction • Birth weight

Introduction

Prenatal smoking is a key contributor to poor infant health in developed countries. Since the seminal work of Simpson [1], a number of studies have consistently found prenatal smoking is associated with a reduction of birth weight of offspring by 150–250 grams (g) [2]. In addition, previous research has also linked smoking during pregnancy to many other adverse birth outcomes such as low birth weight, preterm birth, intrauterine growth retardation, placental abruption, and sudden infant death syndrome [3– 5]. Despite voluminous evidence on the smoking's harmful impacts on infant health, the prevalence of maternal smoking is still quite high in industrial countries [6]. Tong et al. [7] finds about 22–24 % of women in the United States smoked just before or during pregnancy in 2000–2005. In the same period, 33–35 % of women across the United Kingdom (UK) reported smoking prior to or during pregnancy, and about 60 % of these smokers had smoked throughout pregnancy [8].

Given the large percentage of prenatal smokers and the detrimental impacts of maternal smoking on infants, policies to encourage smoking cessation are increasingly being pursued. The UK government has set reduction in prenatal smoking as a top priority for National Health Service (NHS) [9]. The NHS has provided comprehensive cessation services to female smokers who are either pregnant or are planning a pregnancy, because both smoking cessation and reduction can substantially mitigate the smoking associated deficits in birth outcomes [10, 11]. These services provided by the NHS include a variety of recommended strategies, such as individual counseling, group behavior therapy, pharmacotherapies, and telephone quit-lines [12]. Similar strategies are used in other industrial countries such as the United States [13, 14].

The guidance for the wide range of cessation treatments, however, has been vague in the timing issue of prenatal smoking cessation or reduction. No guideline for health professional has stated by what month during pregnancy prenatal smokers should quit to ensure that mothers deliver infants of the same weight as those infants of nonsmokers. Similarly, no guideline has specified by what time during pregnancy persistent smokers should reduce smoking intensity to significantly mitigate the adverse impact of smoking on infant health. The importance of the timing issue cannot be understated. A well specified deadline in pregnancy for women to cut smoking can significantly improve the efficacy of any prenatal smoking cessation intervention [15, 16].

To date, the literature has provided conflicting results on how the timing of prenatal smoking cessation affects birth outcomes especially birth weight. Some studies demonstrate infants of women who quit smoking by the seventh month during pregnancy weigh the same as those infants of nonsmokers [17–19]. However, Macarthur and Knox [20] show that smoking cessation by the end of the second trimester only mitigates the harmful impact of smoking on newborn birth weight. Several other studies suggest women must quit before the second trimester to make fetal exposure to smoking have a negligible effect on infant health [21–24]. Similarly, limited evidence has been reported on the timing of prenatal smoking reduction [17, 19]. In summary, no consensus has been reached on whether the beginning of the second or third trimester is the threshold for the initiation of acute fetal response to smoking.

One limitation of all the above studies is that the datasets used only identify maternal smoking status a few times during or prior to pregnancy. Given the lack of data, these studies are unable to adequately evaluate the effects of stopping or reducing cigarette use by different stages especially different months of a pregnancy. In addition, most of the data in the previous studies are highly selective (from a few hospitals or regions) and lack of important parental socioeconomic control variables. Our research advances the literature by presenting a full dynamics of the timing of fetal exposure to smoking in relation to infant birth weight. We use a unique UK birth cohort dataset which contains information on maternal smoking status month by month during pregnancy. The dataset is also a representative sample of all the UK pregnant women, which provides a rich set of infant, parental, and family level covariates. All these advantages of our dataset provide a unique opportunity to investigate the timing issue on prenatal smoking cessation and reduction.

Methods

Study Design and Population

Our study uses data from the first wave of the UK Millennium Cohort Study (MCS). MCS is an on-going population based survey which tracks a large child cohort from birth throughout childhood into adolescence. Our research uses a random sample of infants (aged 9 months on average) from the first wave of MCS drawn from all the live births in the UK during 2000 and 2001. This cohort was disproportionately stratified to ensure adequate representation of all the four UK countries. As a secondary analysis of anonymized data, our study is conducted in accord with prevailing ethical principles.

We construct two samples in this research, one on prenatal smoking cessation and the other on smoking reduction. In constructing the smoking cessation sample, we start with 13,495 women who answered all the survey questions, reported their histories of cigarette use, and provided complete information on their demographic characteristics. Then we exclude the following observations: missing data on infant birth weight (n = 30); women with multiple births (n = 240); women with preconception health risk factors (cancer, diabetes, hypertension, and asthma) known to affect prenatal smoking cessation by impairing fetal growth [19, 22] (n = 642); women using other tobacco products such as cigar or roll-ups (n = 361); missing data of family income (n = 825), and missing information on who else was present at the baby's birth (n = 266). The final sample has 11,131 mothers with singleton births. Similar exclusion conditions are applied to construct our second sample of smoking reduction. This sample, which has 2,306 smokers, is limited to persistent smokers who never quit smoking but may change the number of daily cigarettes smoked during pregnancy.

Measures

Women who participated in the first wave of MCS were asked a series of questions on tobacco use including whether the respondents had ever smoked, the type of tobacco products they had used, the number of cigarettes they had smoked per day before pregnancy, the month of the pregnancy they had changed the daily cigarette consumption, and the daily number of cigarettes smoked after this change. In the smoking cessation sample, we classify women as: nonsmokers (the reference group), preconception quitters who stopped smoking before pregnancy, month ''j'' quitters who gave up smoking in pregnancy month ''j'' (j = 1, 2,…, 7), and beyond-month-seven smokers who ceased smoking after the seventh month or smoked throughout pregnancy. Only a few mothers in the sample quit smoking after the seventh month, giving little statistical power to estimate the impact of cessation in either the eighth or ninth month. Therefore, we group mothers who quit smoking in the eighth or ninth month with persistent smokers. Grouping these late quitters with persistent smokers is innocuous to explore the deadline month of smoking cessation, since all the previous studies indicate prenatal smoking should have substantially impaired infant health before the eighth month [17–23].

In the smoking reduction sample, we classify persistent smokers into seven categories. The first is our reference group of persistent light smokers who smoked no more than 10 cigarettes daily throughout pregnancy [17]. The second through sixth categories are women who reduced the number of daily cigarettes smoked to less than 10 in month ‘‘k’’ (k = 1, 2,…,5). Our last category consists of mothers who smoked persistently throughout pregnancy and only reduced daily smoking intensity to less than 10 after the fifth month and mothers who never reduced smoking to less 10 cigarettes per day in pregnancy. Again, due to the small number of the women who reduced smoking beyond the fifth month, we group them with persistent heavy smokers. Lastly, in our following analysis, prenatal smokers are also re-categorized by the trimester of smoking cessation or reduction to provide additional insights.

We choose infant birth weight as the outcome of primary interest. Birth weight is the most frequently used measure on infant health. Past studies have shown increasing infant birth weight causally improves childhood health, cognitive development, and adulthood educational attainment and earnings [25–28]. Our research also examines two additional infant health measures strongly associated with prenatal smoking: low birth weight (birth weight < 2,500 g, henceforth LBW) and preterm birth (gestation < 37 weeks). Such two poor birth outcomes not only impose large economic costs for the individuals and the society, but also have lasting impacts on a variety of lifetime outcomes [5, 24, 28]. Because the original survey questionnaire does not code gestational age, we have to use estimated gestational age derived by the MCS team in 2004 which makes it difficult to precisely identify all the preterm births, admittedly a limitation.

We include many potential determinants on infant health other than smoking in the baseline regression: birth characteristics (infant male, parity, birth year/quarter), parental demographics (age, race, ethnicity, and education), maternal socioeconomic status (marital status, prenatal care initiation in the first trimester, family income measured by OECD equivalised monthly income, and father present at the baby’s birth), and maternal health status and behavior (preconception height and weight, any alcohol use during pregnancy). We use the indicator on father’s presence at a baby’s birth to capture paternal involvement in pregnancy such as a father’s willingness to devote resources to fetal development. For instance, an expectant father can help improving infant health by making his spouse/partner quit smoking timely during pregnancy. For robustness checks, we further control for the following mother level variables: having a job during pregnancy, receiving any benefits, being satisfied about the current home, religion affiliations, frequent alcohol use during pregnancy (alcohol use at least three times a week), and indicators of racist and religion-based insults in mothers’ living areas.

In Table 1, we present the summary statistics of the three dependent variables and the key covariates used in the baseline regression. The descriptive statistics of the additional controls in sensitivity analysis are not reported to save space. In Column (1) we focus on the full sample of smoking cessation. In Columns (2) to (5), we stratify this whole sample into four subsamples by the trimester of smoking cessation. The first three rows indicate the birth outcomes of the mothers who stopped smoking in the first trimester were similar to the nonsmokers. Mothers who smoked beyond the first trimester, however, had much worse birth outcomes than the nonsmokers and trimester 1 quitters.

The means in other rows show the control variables also vary by smoker type. Compared with nonsmokers, preconception quitters, and trimester 1 quitters, mothers who smoked through the second trimesters had lower educational attainment and lower family income, were less likely to be married and initiate prenatal care in the first trimester, and were more likely to use alcohol during pregnancy. Although almost all the sampled mothers are UK citizens or foreigners living lawfully in UK and thereby entitled to free prenatal care under the UK universal healthcare system, we find marked variation in the timing of prenatal care initiation across nonsmokers and different types of smokers. In general, mothers of low socioeconomic status tended to delay smoking cessation in pregnancy. Since birth outcomes are also affected by socioeconomic status variables, controlling for these covariates (education, income, and marital status) is important to disentangle the independent impact of smoking cessation on infant health [17, 22–24]. Finally, in Column (6) we report the summary statistics of the smoking reduction sample.

In Fig. 1, we show the average birth weights of the infants of nonsmokers and smokers who differ in the month of smoking cessation. We find birth outcomes of nonsmokers and preconception quitters were similar and so we use them as the base for comparison. We also find infants born to mothers who ceased smoking in the first three pregnancy months weighed almost the same as infants of nonsmokers or preconception quitters. However, infants delivered by mothers who quit smoking in the fourth month weighed 120–160 g less than infants born to mothers who quit smoking earlier or never smoked. In addition, smoking beyond the fourth month was further associated with a decrease in infant birth weight by about 50–100 g.

In Fig. 2, we report the average infant birth weights by grouping mothers by the trimester of smoking cessation. We find, when mothers gave up smoking in the first trimester, their infants weighed nearly the same as infants of nonsmokers or preconception quitters. In contrast, mothers who smoked through the second trimester had infants with much lower birth weights. This preliminary comparison of means in the two figures suggests that prenatal smokers have to quit by the third month to avoid the initiation of acute fetal response to smoking. We find similar results in the graphical analysis on smoking reduction among persistent smokers (not shown).

Statistical Analysis

We use multiple linear regressions to study the relationship between the timing of prenatal smoking cessation or reduction and infant birth weight. Our benchmark specification controls for the basic confounding factors. We then include a number of additional covariates for robustness checks. As another sensitivity analysis, we implement four variable selection procedures rarely used in this literature: forward selection, backward selection, forward stepwise selection, and backward stepwise selection.

Table 1 Summary statistics of the dependent variables and key covariates

	(1) Full sample of smoking cessation		(2) No cigarette use before or during pregnancy		(3) Cessation before pregnancy or in trimester 1		(4) Cessation in trimester 2		(5) Cessation in trimester 3 or no cessation		(6) Full Sample of smoking reduction	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	All	SD
Infant birth weight (grams)	3377.13	574.09	3452.03	550.73	3440.52	581.79	3267.91	625.11	3190.68	571.60	3208.04	556.35
Low birth weight	0.06	0.24	0.04	0.20	0.05	0.21	0.09	0.29	0.10	0.30	0.09	0.29
Preterm birth	0.07	0.25	0.06	0.23	0.06	0.24	0.09	0.29	0.09	0.29	0.08	0.27
Infant male	0.51	0.50	0.51	0.50	0.51	0.50	0.52	0.50	0.53	0.50	0.54	0.50
Parity	0.93	1.07	0.92	1.03	0.70	0.93	0.53	0.73	1.12	1.22	0.99	1.12
Asian mother	0.06	0.23	0.09	0.29	0.02	0.14	0.02	0.12	0.01	0.10	0.01	0.11
Black mother	0.02	0.14	0.03	0.16	0.02	0.15	0.02	0.15	0.01	0.11	0.01	0.12
Asian father	0.06	0.23	0.09	0.28	0.02	0.14	0.02	0.12	0.02	0.13	0.02	0.14
Black father	0.03	0.16	0.03	0.16	0.03	0.18	0.04	0.19	0.02	0.15	0.02	0.15
Mother's education = O level	0.36	0.48	0.33	0.47	0.42	0.49	0.37	0.49	0.38	0.48	0.40	0.49
Mother's education $\geq$ A level	0.35	0.48	0.48	0.50	0.31	0.46	0.23	0.42	0.12	0.33	0.14	0.34
Mother's age <20	0.09	0.29	0.04	0.19	0.14	0.35	0.34	0.48	0.16	0.37	0.17	0.38
Mother's age between 20 and 30	0.46	0.50	0.41	0.49	0.51	0.50	0.44	0.50	0.53	0.50	0.54	0.50
Father's age <30	0.40	0.49	0.30	0.46	0.49	0.50	0.63	0.48	0.53	0.50	0.55	0.50
Father's age between 30 and 40	0.51	0.50	0.59	0.49	0.44	0.50	0.31	0.47	0.38	0.49	0.37	0.48
Mother married	0.58	0.49	0.75	0.43	0.46	0.50	0.27	0.45	0.33	0.47	0.33	0.47
Father present at the baby's birth	0.85	0.35	0.90	0.30	0.85	0.36	0.76	0.43	0.76	0.43	0.76	0.42
Mother living in Wales	0.16	0.37	0.15	0.35	0.17	0.38	0.20	0.40	0.19	0.39	0.18	0.38
Mother living in North Ireland	0.11	0.32	0.11	0.31	0.10	0.30	0.11	0.31	0.14	0.35	0.14	0.35
Mother living in Scotland	0.14	0.35	0.14	0.35	0.13	0.34	0.11	0.32	0.15	0.35	0.15	0.36
Preconception eight (kilograms)	63.28	12.08	64.15	12.1	63.21	11.99	60.1	11.07	61.66	11.95	61.29	11.63
Preconception height (meters)	1.64	0.07	1.64	0.07	1.64	0.07	1.64	0.06	1.63	0.07	1.63	0.07
OECD equivalised income (£)	318.59	239.3	377.35	254.58	308.38	230.62	236.17	194.67	207.7	159.22	216.26	170
First prenatal care in trimester 1	0.73	0.45	0.76	0.43	0.74	0.44	0.51	0.50	0.67	0.47	0.67	0.47
Any alcohol use during pregnancy	0.31	0.46	0.30	0.46	0.35	0.48	0.34	0.48	0.32	0.47	0.32	0.47
Number of observations	11,131		6,192		1,789		131		3,019		2,306	

Source the UK Millennium Cohort Study (wave 1)

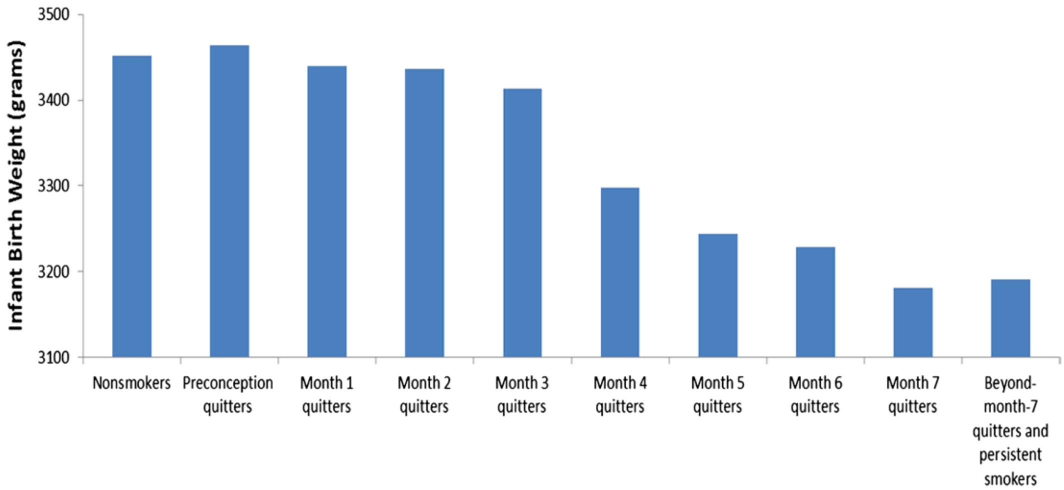

Fig. 1 Timing of prenatal smoking cessation (by month) and infant birth weight

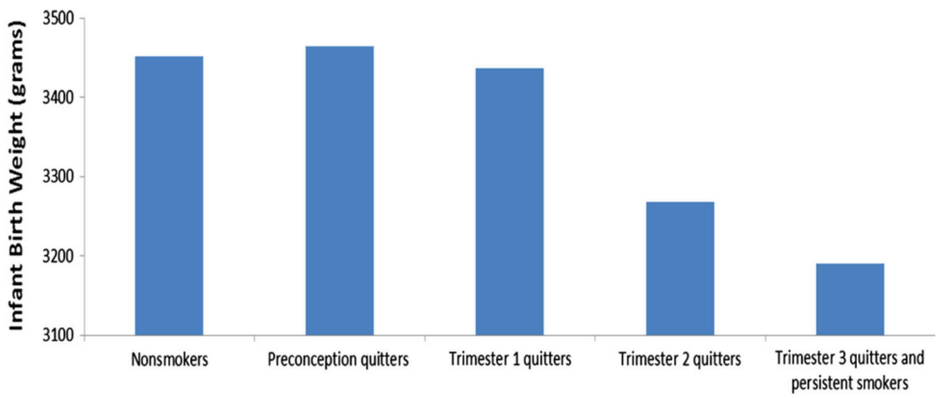

Fig. 2 Timing of prenatal smoking cessation (by trimester) and infant birth weight

Our first procedure is forward selection. We start with adding the most significant explanatory variable into an initial model with no input, then continue adding variables until none of the remaining variables are significant at 10 % ($p < 0.1$). In contrast, a backward selection keeps eliminating insignificant explanatory variables until the p-values of the remaining variables are all < 0.1. In a forward stepwise selection, explanatory variables once entered may be dropped, if they are not significant at 10 % as other variables are included. Finally, a backward stepwise selection starts with a backward selection procedure, and then adds back variables dropped earlier if they later on appear to be significant. To the best of our knowledge, only two studies in this large literature [19, 29] have used forward and backward selection procedures and none has applied the two stepwise methods.

Table 2 Timing of prenatal smoking cessation (by month) and infant birth weight

Variable	Infant birth weight							
	(1) Basic controls		(2) Full controls		(3) Forward selection		(4) Backward selection	
	Estimate	p value	Estimate	p value	Estimate	p value	Estimate	p value
Smoking cessation before pregnancy	−8.36	0.69	−8.39	0.69				
Smoking cessation in month 1	−6.38	0.66	−4.86	0.74				
Smoking cessation in month 2	−5.99	0.86	−5.35	0.87				
Smoking cessation in month 3	−10.76	0.72	−9.32	0.74				
Smoking cessation in month 4	−140.37**	0.03	−142.67**	0.03	−142.94**	0.02	−142.94**	0.02
Smoking cessation in month 5	−175.36**	0.01	−169.61**	0.01	−169.19***	0.01	−169.19***	0.01
Smoking cessation in month 6	−188.84*	0.08	−184.49*	0.08	−186.04*	0.07	−186.04*	0.07
Smoking cessation in month 7	−216.57**	0.05	−215.44**	0.05	−199.11*	0.08	−199.11*	0.08
Smoking cessation after month 7 or no cessation	−248.23***	0.00	−245.29***	0.00	−247.99***	0.00	−247.99***	0.00
Infant male	134.06***	0.00	134.48***	0.00	134.41***	0.00	134.41***	0.00
Parity	47.11***	0.00	49.78***	0.00	45.86***	0.00	45.86***	0.00
Asian mother	−186.88**	0.03	−216.76**	0.03	−209.62**	0.04	−209.62**	0.04
Black mother	−83.23*	0.06	−91.42*	0.05	−129.04***	0.01	−129.04***	0.01
Asian father	−130.48*	0.06	−138.20**	0.03	−135.56**	0.04	−135.56**	0.04
Black father	−47.57	0.45	−48.92	0.44				
Mother's education = O level	14.98	0.11	12.11	0.19	16.21*	0.10	16.21*	0.10
Mother's education $\geq$ A level	44.21***	0.01	40.30**	0.02	46.73***	0.01	46.73***	0.01
Mother's age $<$20	76.97***	0.00	83.65***	0.01	47.39***	0.01	47.39***	0.01
Mother's age between 20 and 30	25.91	0.21	27.87	0.22				
Father's age $<$30	47.33**	0.02	46.22**	0.03	55.98**	0.02	55.98**	0.02
Father's age between 30 and 40	34.91*	0.07	33.86*	0.06	39.37*	0.05	39.37*	0.05
Mother married	32.75	0.12	27.76	0.23				
Father present at the baby's birth	101.01**	0.01	99.55**	0.02	106.78***	0.01	106.78***	0.01
Mother living in Wales	−7.94*	0.10	−6.32	0.19				
Mother living in North Ireland	52.39***	0.00	35.58**	0.02	53.46***	0.00	53.46***	0.00
Mother living in Scotland	36.03***	0.00	33.46***	0.01	43.09***	0.00	43.09***	0.00
Number of observations	11,131		11,131		11,131		11,131	

The regression in Column (1) also adjusts for preconception weight, preconception height, family income, prenatal care initiation in the first trimester, any alcohol use during pregnancy, and infant birth year/quarter effects. The regression in Column (2) additionally controls for having a job during pregnancy, receiving any benefits (jobseekers allowance, income support, working family tax credits, or disabled persons tax credits), being satisfied about the current home, religion affiliations, frequent alcohol use during pregnancy, indicators of racist and religion-based insults in mothers' living areas. Column (3) applies a forward selection on all the control variables used in Column (2). Column (4) applies a backward selection on all the control variables. p values are reported in the parentheses and *** means statistically significant at 1 % ($p < 0.01$), ** significant at 5 % ($p < 0.05$), * significant at 10 % ($p < 0.1$)

Each selection procedure screens all the explanatory variables including smoking measures, which gives a subset of those variables with significant explanatory power on infant birth weight. If a certain month is the threshold when smoking begins to adversely affect infant birth weight, then the indicator of smoking cessation in this month should survive every variable selection procedure. The same thought applies to determining the threshold month of prenatal smoking reduction.

Table 3 Timing of prenatal smoking cessation (by trimester) and infant birth weight

Variable	Infant birth weight							
	(1) Basic controls		(2) Full controls		(3) Forward selection		(4) Backward selection	
	Estimate	*p* value	Estimate	*p* value	Estimate	*p* value	Estimate	*p* value
Smoking cessation before pregnancy	−8.34	0.69	−8.37	0.69				
Smoking cessation in trimester 1	−6.75	0.68	−5.51	0.73				
Smoking cessation in trimester 2	−160.43***	0.00	−158.94***	0.00	−159.31***	0.00	−159.31***	0.00
Smoking cessation in trimester 3 or no cessation	−248.13***	0.00	−245.20***	0.00	−247.91***	0.00	−247.91***	0.00
Infant male	134.04***	0.00	134.47***	0.00	134.41***	0.00	134.41***	0.00
Parity	47.11***	0.00	49.78***	0.00	45.85***	0.00	45.85***	0.00
Asian mother	−186.75**	0.03	−216.71**	0.03	−209.59**	0.04	−209.59**	0.04
Black mother	−83.11*	0.06	−91.34*	0.05	−129.07***	0.01	−129.07***	0.01
Asian father	−130.58*	0.06	−138.32**	0.03	−135.70**	0.04	−135.70**	0.04
Black father	−47.75	0.45	−49.10	0.44				
Mother's education = O level	14.99	0.12	12.13	0.19	16.24*	0.10	16.24*	0.10
Mother's education ≥ A level	44.21***	0.01	40.32**	0.02	46.76***	0.01	46.76***	0.01
Mother's age <20	77.05***	0.00	83.73***	0.01	47.57***	0.01	47.57***	0.01
Mother's age between 20 and 30	25.97	0.21	27.91	0.22				
Father's age <30	47.28**	0.02	46.17**	0.03	55.98**	0.02	55.98**	0.02
Father's age between 30 and 40	34.93*	0.07	33.86*	0.06	39.40*	0.05	39.40*	0.05
Mother married	32.80	0.12	27.83	0.22				
Father present at the baby's birth	100.97**	0.01	99.51**	0.02	106.70***	0.01	106.70***	0.01
Mother living in Wales	−7.88*	0.08	−6.28	0.17				
Mother living in North Ireland	52.47***	0.00	35.61**	0.02	53.46***	0.00	53.46***	0.00
Mother living in Scotland	35.99***	0.00	33.42***	0.01	43.00***	0.00	43.00***	0.00
Number of observations	11,131		11,131		11,131		11,131	

The regression in Column (1) also adjusts for preconception weight, preconception height, family income, prenatal care initiation in the first trimester, any alcohol use during pregnancy, and infant birth year/quarter effects. The regression in Column (2) additionally controls for having a job during pregnancy, receiving any benefits (jobseekers allowance, income support, working family tax credits, or disabled persons tax credits), being satisfied about the current home, religion affiliations, frequent alcohol use during pregnancy, indicators of racist and religion-based insults in mothers' living areas. Column (3) applies a forward selection on all the control variables used in Column (2). Column (4) applies a backward selection on all the control variables. *p* values are reported in the parentheses and *** means statistically significant at 1 % ($p < 0.01$), ** significant at 5 % ($p < 0.05$), * significant at 10 % ($p < 0.1$)

Results

In Table 2, we address the impact of prenatal smoking cessation by month on infant birth weight. In Column (1), we show the estimated impacts of smoking cessation before or in the first 3 months of pregnancy are all small and insignificant. However, stopping cigarette use as late as the fourth month (the threshold month) significantly reduces infant birth weight by 140 g (p = 0.03). We find smoking cessation between the fifth and seventh month during pregnancy leads to larger reductions in birth weight which range from 175 to 217 g. If mothers smoke beyond the seventh month, then their babies will weigh about 249 g less than infants born to nonsmokers (p < 0.01). In Column (1), we also find newborn babies are of higher weight if their mothers are more educated, younger, married, living in North Ireland or Scotland, or if their fathers are younger than 40 and present at babies' births.

We find the results in Column (2) are very similar to Column (1), when additional confounding factors are controlled for. We then implement the four variable selection approaches, all of which provide identical results. To save room, we only report the outcomes of a forward selection and backward selection procedure in Columns (3) and (4). In all the four selection procedures, we find the four indicators of smoking cessation before the fourth month are dropped, suggesting mothers who quit before the fourth month have infants of the same birth weight as nonsmokers. In contrast, we find smoking cessation in the fourth month is always a significant predictor of having babies of lower weights (p = 0.02). The indicators of smoking beyond the fourth month are also selected into the final models. Overall, our results suggests prenatal smokers must quit by the end of the first trimester (before the fourth month threshold) to nullify the adverse smoking impact on newborn babies.

Table 4 Timing of prenatal smoking reduction (by month or trimester) and infant birth weight

Variable	Infant birth weight							
	(1) Basic controls		(2) Full controls		(3) Forward selection		(4) Backward selection	
	Estimate	*p* value	Estimate	*p* value	Estimate	*p* value	Estimate	*p* value
Smoking reduction in month 1	−14.83	0.65	−16.20	0.59				
Smoking reduction in month 2	−13.28	0.67	−20.10	0.54				
Smoking reduction in month 3	−9.64	0.77	−16.92	0.61				
Smoking reduction in month 4	−58.24**	0.03	−56.00**	0.04				
Smoking reduction in month 5	−76.75	0.33	−84.94	0.31				
Smoking reduction after month 5 or no reduction	−89.07**	0.05	−88.24*	0.06				
Smoking reduction in trimester 1					−13.03	0.56	−18.19	0.42
Smoking reduction in trimester 2					−65.17*	0.05	−66.20**	0.04
Smoking reduction in trimester 3 or no reduction					−89.79*	0.07	−88.19*	0.08
Infant male	152.97***	0.00	149.46***	0.00	152.89***	0.00	149.32***	0.00
Parity	14.64	0.17	21.98*	0.06	14.82	0.14	22.08**	0.05
Asian mother	−237.30**	0.01	−83.47	0.52	−236.44**	0.01	−82.98	0.52
Black mother	59.27	0.43	51.52	0.52	59.41	0.43	51.99	0.52
Asian father	−177.16***	0.01	−110.31*	0.07	−178.48***	0.01	−112.24*	0.08
Black father	−57.91	0.38	−67.41	0.32	−58.00	0.39	−67.40	0.33
Mother's education = O level	38.05	0.13	22.50	0.38	38.14	0.14	22.90	0.38)
Mother's education ≥ A level	67.19**	0.04	47.42	0.16	67.23**	0.04	47.70	0.16
Mother's age <20	85.75*	0.07	107.11**	0.03	86.12*	0.07	107.28**	0.03
Mother's age between 20 and 30	76.08***	0.00	89.90***	0.00	76.32***	0.00	90.06***	0.00
Father's age <30	−8.00	0.85	−16.03	0.69	−8.02	0.84	−16.15	0.69
Father's age between 30 and 40	−72.32	0.11	−75.24*	0.09	−72.32	0.11	−75.25*	0.09
Mother married	80.97**	0.02	73.70**	0.04	80.73**	0.02	73.63**	0.03
Father present at the baby's birth	30.87	0.37	33.50	0.36	31.03	0.37	33.70	0.36
Mother living in Wales	8.91	0.58	7.28	0.62	8.70	0.59	7.19	0.63
Mother living in North Ireland	57.00***	0.01	16.28	0.67	57.15***	0.01	16.66	0.66
Mother living in Scotland	37.16	0.42	29.31	0.52	37.00	0.42	29.26	0.52
Number of observations	2,306		2,306		2,306		2,306	

The regressions in Columns (1) and (3) also adjust for preconception weight, preconception height, family income, prenatal care initiation in the first trimester, any alcohol use during pregnancy, and infant birth year/quarter effects. The regressions in Columns (2) and (4) additionally control for having a job during pregnancy, receiving any benefits (jobseekers allowance, income support, working family tax credits, or disabled persons tax credits), being satisfied about the current home, religion affiliations, frequent alcohol use during pregnancy, indicators of racist and religion-based insults in mothers' living areas. *p* values are reported in the parentheses and *** means statistically significant at 1 % ($p < 0.01$), ** significant at 5 % ($p < 0.05$), * significant at 10 % ($p < 0.1$)

In Table 3, we study the relationship between smoking cessation by trimester and infant birth weight. In Column (1), we find when mothers quit smoking prior to pregnancy or in the first trimester, fetal exposure to smoking will have a negligible effect on birth weight. Smoking cessation in the second trimester, however, is still significantly associated with much lower birth weights by 160 g ($p < 0.01$). In addition, we find smoking beyond the second trimester reduces birth weight by 248 g ($p < 0.01$). Comparing the two estimates, we find two-thirds of the total deleterious smoking impact on infant birth weight occurs in the second trimester. Our results are robust in the presence of additional covariates in Column (2) and with two variable selection procedures in Columns (3) and (4). The estimates of the two stepwise selection approaches (not reported) are the same as Columns (3) and (4). Although several past studies find that mothers can postpone smoking cessation until the end of the second trimester to deliver infants of the same weight as infants of nonsmokers [17–19], our results in Tables 2 and 3 present robust counter evidence. In Table 4, we examine how the timing of smoking reduction affects birth weights of infants born to persistent smokers. In Column (1), we show if mothers substantially reduce smoking intensity in the first 3 months during pregnancy, their infants will be indistinguishable from babies of the persistent light smokers in term of birth

Table 5 Timing of prenatal smoking cessation (by month or trimester) and two alternative birth outcomes

Variable	Low birth weight				Preterm birth			
	(1) By month		(2) By trimester		(3) By month		(4) By trimester	
	Estimate	p value	Estimate	p value	Estimate	p value	Estimate	p value
Smoking cessation before pregnancy	−0.001	0.91	0.003	0.72	0.008	0.57	0.008	0.15
Smoking cessation in month 1	0.003	0.55			0.010	0.30		
Smoking cessation in month 2	−0.000	0.97			−0.009	0.50		
Smoking cessation in month 3	−0.011	0.42			−0.013	0.42		
Smoking cessation in month 4	0.045*	0.07			0.029*	0.09		
Smoking cessation in month 5	0.047	0.21			0.029	0.65		
Smoking cessation in month 5 or no cessation	0.049***	0.00			0.029***	0.00		
Smoking cessation in trimester 1			0.004	0.55			0.001	0.80
Smoking cessation in trimester 2			0.046**	0.01			0.028*	0.08
Smoking cessation in trimester 3 or no cessation			0.053***	0.00			0.029***	0.00
Infant male	−0.016***	0.00	−0.016***	0.01	0.004	0.45	0.004	0.19
Parity	−0.007*	0.05	−0.006**	0.04	0.002	0.43	0.002	0.15
Asian mother	0.054**	0.03	0.053	0.12	0.021**	0.05	0.022***	0.00
Black mother	0.020**	0.01	0.019	0.33	−0.020***	0.00	−0.022***	0.00
Asian father	0.017	0.30	0.017	0.38	0.005	0.78	0.004	0.28
Black father	0.006	0.56	0.008	0.71	0.019	0.16	0.018***	0.00
Mother's education = O level	−0.006	0.34	−0.006	0.29	0.010	0.30	0.010***	0.01
Mother's education ≥ A level	−0.017**	0.03	−0.017***	0.01	−0.000	0.99	−0.000	0.96
Mother's age <20	−0.031***	0.00	−0.031***	0.00	0.014	0.24	0.013	0.14
Mother's age between 20 and 30	−0.013**	0.03	−0.012***	0.01	0.002	0.65	0.002	0.70
Father's age <30	−0.018***	0.00	−0.018	0.16	−0.019**	0.02	−0.020**	0.03
Father's age between 30 and 40	−0.009***	0.01	−0.010	0.26	−0.005	0.48	−0.005	0.51
Mother married	−0.004	0.57	−0.004	0.52	−0.004	0.45	−0.004	0.42
Father present at the baby's birth	−0.029**	0.02	−0.030**	0.04	−0.029***	0.01	−0.033***	0.00
Mother living in Wales	−0.004	0.25	−0.004	0.42	−0.006***	0.01	−0.006**	0.01
Mother living in North Ireland	−0.008**	0.04	−0.009	0.18	−0.006	0.12	−0.006	0.18
Mother living in Scotland	−0.009***	0.00	−0.009*	0.05	−0.007*	0.09	−0.007	0.15
Number of observations	11,131		11,131		11,131		11,131	

All the regressions in Columns (1) to (4) additionally adjust for preconception weight, preconception height, family income, prenatal care initiation in the first trimester, any alcohol use during pregnancy, and infant birth year/quarter effects, having a job during pregnancy, receiving any benefits (jobseekers allowance, income support, working family tax credits, or disabled persons tax credits), being satisfied about the current home, religion affiliations, frequent alcohol use during pregnancy, indicators of racist and religion-based insults in mothers' living areas. p values are reported in the parentheses and *** means statistically significant at 1 % ($p < 0.01$), ** significant at 5 % ($p < 0.05$), * significant at 10 % ($p < 0.1$)

weight. However, we find switching from heavy to light smoking as late as the fourth month still leads to lower infant birth weights by 58 g (p = 0.03). Heavy smoking beyond the fourth month further decreases infant birth weight by 19–31 g. When we add additional covariates in Column (2), the results are very similar. In Columns (3) and (4), we present estimates on smoking reduction by trimester. In both columns we find heavy smokers have to reduce smoking intensity before the second trimester, in order to deliver infants who weigh the same as infants born to the persistent light smokers. Our results are robust to the four variable selection approaches (not shown for brevity). To summarize, we find even if some heavy smokers cannot completely quit smoking during pregnancy, they can substantially mitigate the detrimental smoking impact on infant birth weight through reducing smoking intensity by the end of the first trimester.

In Table 5, we report the estimated impacts of the timing of smoking cessation on LBW and preterm birth. Because of the low prevalence of the two birth outcomes and the small number of mothers who stopped smoking after the fifth month, we group those late quitters with persistent smokers to increase statistical power. In Columns (1) and (3), we show smoking cessation by the third month during pregnancy does not significantly increase the risks of LBW and preterm birth. However, smoking cessation in the fourth month still leads to significantly higher risks of LBW ($p = 0.07$) and preterm birth ($p = 0.09$), consistent with the results on birth weight in Table 2. In Columns (2) and (4), our results indicate while smoking cessation by the first trimester nullifies the impacts of smoking on the two poor birth outcomes, smoking cessation beyond the first trimester significantly increases the incidences of LBW ($p = 0.01$) and preterm birth ($p = 0.08$). We also examine the relationship between smoking reduction and the two birth outcomes. Since the small sample of smoking reduction provides low statistical power even when smokers are grouped by trimester, the regression estimates are nearly all insignificant. Nevertheless, when we test for the differences of means, these tests show mothers who smoke heavily through the fourth month are significantly more likely to have LBW or preterm birth babies than those mothers who reduce smoking intensity by the third month ($p < 0.1$). The results are available upon request.

In Table 6, we conduct several subsample analyses, with all the control variables added into regressions. In Column (1), we limit the sample to nonsmokers, preconception quitters, and trimester 1 quitters. Our results show the effects of smoking cessation before or in the first 3 months of pregnancy on birth weight are small and insignificant. In Column (2), we restrict the sample to nonsmokers, preconception quitters, trimester 2/3 quitters and persistent smokers. We find smoking through the fourth month (the beginning of the second trimester) reduces birth weight by 141–244 g ($p < 0.1$). Our results are very close to Table 2. In Columns (3) and (4), we focus on two stratified subsamples of England and other UK countries, respectively. We find the results in both columns are again consistent with Table 2. Finally, we find the benchmark estimates in Column (2) of Tables 2 and 4 are virtually unchanged, when we further control for an indicator of urban areas and another indicator on high barriers to hospital care, with the results available upon request.

Table 6 Timing of prenatal smoking cessation and infant birth weight: subsample analyses

Variable	Infant birth weight							
	(1) Trimester 1 plus preconception quitters		(2) Trimester 2/3 quitters plus persistent smokers		(3) England		(4) Other UK countries	
	Estimate	*p* value	Estimate	*p* value	Estimate	*p* value	Estimate	*p* value
Smoking cessation before pregnancy	−9.85	0.69			−10.66	0.57	2.78	0.95
Smoking cessation in month 1	−1.00	0.95			0.10	1.00	4.64	0.74
Smoking cessation in month 2	−0.59	0.99			18.15	0.72	−23.50	0.37
Smoking cessation in month 3	−9.37	0.80			−1.91	0.97	−12.86	0.83
Smoking cessation in month 4			−141.03**	0.03	−138.54*	0.08	−155.99*	0.10
Smoking cessation in month 5			−168.36**	0.01	−164.98**	0.01	−158.13***	0.00
Smoking cessation in month 6			−179.26*	0.08	−242.49***	0.00	−169.59	0.23
Smoking cessation in month 7			−218.22**	0.03	−247.95***	0.01	−171.28***	0.00
Smoking cessation after month 7 or no cessation			−244.30***	0.00	−248.92***	0.01	−222.90***	0.00
Infant male	133.62***	0.00	131.54***	0.00	133.61***	0.00	135.01***	0.00
Parity	66.53***	0.00	50.62***	0.00	54.02***	0.00	47.58***	0.00
Asian mother	−282.72**	0.02	−198.88*	0.06	−131.36	0.33	−218.53*	0.06
Black mother	−120.90**	0.04	−81.89**	0.03	−102.51*	0.09	212.85***	0.00
Asian father	−168.15**	0.02	−153.23**	0.02	−97.99	0.18	−192.60***	0.00
Black father	−38.72	0.57	−38.70	0.56	−74.39	0.37	146.42**	0.03
Mother's education = O level	17.62	0.31	19.27*	0.08	0.61	0.94	31.05	0.16
Mother's education ≥ A level	60.40**	0.02	37.80**	0.05	41.56*	0.07	37.80	0.18
Mother's age <20	23.61	0.42	81.69**	0.02	63.73	0.19	107.68**	0.02
Mother's age between 20 and 30	13.36	0.44	28.24	0.19	22.96	0.57	38.48	0.15
Father's age <30	47.79***	0.01	41.05*	0.08	54.94**	0.03	37.37*	0.06
Father's age between 30 and 40	58.00***	0.00	15.09	0.33	33.73	0.14	34.70*	0.06
Mother married	18.41	0.43	40.39	0.14	35.67	0.23	10.08	0.51
Father present at the baby's birth	151.73***	0.00	88.08**	0.04	86.31	0.22	124.29***	0.00
Mother living in Wales	−26.40**	0.04	1.59	0.76				
Mother living in North Ireland	9.42	0.76	42.83**	0.03				
Mother living in Scotland	9.76	0.50	36.15**	0.01				
Number of observations	7,981		9,342		6,467		4,664	

All the regressions in Columns (1) to (4) additionally adjust for preconception weight, preconception height, family income, prenatal care initiation in the first trimester, any alcohol use during pregnancy, and infant birth year/quarter effects, having a job during pregnancy, receiving any benefits (jobseekers allowance, income support, working family tax credits, or disabled persons tax credits), being satisfied about the current home, religion affiliations, frequent alcohol use during pregnancy, indicators of racist and religion-based insults in mothers' living areas. *p* values are reported in the parentheses and *** means statistically significant at 1 % ($p < 0.01$), ** significant at 5 % ($p < 0.05$), * significant at 10 % ($p < 0.1$)

Discussions

Our study uses a large UK birth cohort dataset to shed new light on the relationship between the timing of prenatal smoking cessation or reduction and infant birth weight. We find mothers who quit smoking by the third month during pregnancy (before the fourth month threshold) have infants of the same weight as infants of nonsmokers. We find, however, smoking cessation in the fourth month or any time beyond is associated with substantially lower infant birth weights. Two-thirds of the total adverse smoking impact on infant birth weight occurs in the second trimester. Our study also shows mothers who smoke throughout pregnancy but cut smoking intensity by the third month in pregnancy deliver infants of the same weight as infants born to persistent light smokers. Our findings are robust as we use a rich set of additional covariates, a series of variable selection procedures, alternative birth outcome measures, and stratified samples.

One possible limitation of our study is recall error in smoking cessation or reduction. The number of such errors may be small, since mothers were interviewed a few months after delivering their babies. Due to data limitations, we are unable to address how the timing of smoking cessation or reduction affects other interesting birth outcomes such as crown-heel length, head circumference, and the development of infant brain system. Lastly, this analysis is limited to one birth cohort.

Overall, our findings highlight the importance to incorporate the timing issue into prenatal smoking cessation interventions. Several evaluations show the NHS stop smoking intensive treatments only lead to low quit rates among prenatal smokers [30, 31]. In addition, some recent reviews of randomized clinical cessation trials report the current prenatal smoking programs have had limited success, not only in the UK but also in other developed countries such as the United States [32, 33]. Our research, however, shows at any given rate of smoking cessation or reduction, the efficiency of prenatal smoking cessation programs still can be significantly improved, particularly, if health professionals can curb smoking early in pregnancy especially by the end of the first trimester. At the aggregate level, promotion of timely prenatal smoking cessation and reduction allows policy makers and medical practitioners to significantly reduce the huge costs of poor birth outcomes due to prenatal smoking [34, 35]. Future research can explore the enhanced benefit-ratios of the smoking cessation programs which expedite smoking cessation or reduction in pregnancy, using estimates of our study, savings on healthcare expenses due to improved birth outcomes, and cost estimates of those cessation programs.

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