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Original Investigation

Infant Delivery Costs Related to Maternal Smoking: An Update

Esther Kathleen Adams, Ph.D.,[1] Cathy L. Melvin, Ph.D., M.P.H.,[2] Cheryl Raskind-Hood, M.S., M.P.H.,[1] Peter J. Joski, M.S.P.H.,[3] & Ecaterina Galactionova, M.A.[1]

[1] Department of Health Policy and Management, Rollins School of Public Health, Emory University, Atlanta, GA
[2] Sheps Center for Health Services Research, University of North Carolina, Chapel Hill, NC
[3] Kaiser Permanente of Georgia, Atlanta, GA

Corresponding Author: Esther Kathleen Adams, Ph.D., *Rollins School of Public Health, Emory University, 1518 Clifton Road, NE Room 654, Atlanta, GA 30345, USA. Telephone: 404-727-9370; Fax: 404-727-9198; E-mail: eadam01@sph.emory.edu*

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Abstract

Introduction: Adverse maternal and infant health outcomes due to maternal smoking are well known. Previous estimates of health care costs for infants at delivery attributable to maternal smoking were $366 million, $704 per smoker, in 1996 dollars. Changes in antenatal and neonatal care, medical care inflation, and declines in the prevalence of maternal smoking call for an updated analysis.

Methods: We used Pregnancy Risk Assessment Monitoring System for 2001/2002 to estimate the association of maternal smoking to Neonatal Intensive Care Unit (NICU) admission and, in turn, the length of stay for infants admitted/not admitted. Models are then used with 2003 natality files to derive predicted expenses as is and "as if" mothers did not smoke. The difference in these predicted expenses is smoking attributable expenses (SAEs). The updated analysis incorporated Hispanic ethnicity as an additional variable, data from 27 as opposed to 13 states, and updated (2004) NICU costs per night.

Results: In contrast to earlier work, we find no significant association of maternal smoking and NICU admission but rather, a positive effect on the length of stay of exposed infants once admitted to the NICU. SAEs were estimated at $122 million (*CI* = −$29m to $285m) nationally and $279 (CI = −$76 to $653) per maternal smoker in 2004 dollars.

Conclusions: Declines in maternal smoking prevalence between the mid-1990s and 2003 combined with a weaker relationship of maternal smoking to NICU admission offset medical care inflation such that infants' SAEs declined. Yet, these are significant in magnitude, incurred immediately and highly preventable.

Introduction

Smoking during pregnancy is significantly associated with poor outcomes for both the pregnant woman, such as placenta previa and abruption, and for her unborn child, such as preterm-related death and fetal growth restriction (U.S. Department of Health and Human Services [USDHHS], 2004). Moreover, more maternal smokers have infants who are small for gestational age than mothers who are nonsmokers (Bakketeig et al., 1993; Cnattingius, Forman, Berendes, Graubard, & Isotalo, 1993; USDHHS, 2004). Finally, maternal smoking and environmental smoke have been strongly associated with the probability of dying of Sudden Infant Death Syndrome (DiFranza & Lew, 1995; Schoendorf & Kiely, 1992; Scragg et al., 1993) and with respiratory illness in children (Stoddard & Miller, 1995). Despite these adverse effects, around 10% of 2004 live birth certificates indicated the mother smoked during pregnancy (USDHHS, 2006a). Although this represents a large decline from the 18.4% reported in 1990, at least half of women who enter pregnancy as a smoker continue to smoke through pregnancy (Wakschlag et al., 2003). Little change in rates of postpartum relapse (Colman, Grossman, & Joyce, 2003) means that permanent quits among pregnant women will require additional efforts.

Increasingly, public health care officials as well as employers are seeking preventive actions to reduce smoking and the subsequent avoidable health care costs at a positive rate of return for society (Chapman, 2003). In order to estimate the economic benefits of smoking cessation, policy makers need information on smoking attributable costs. Estimates from the Smoking Attributable Morbidity, Mortality and Economic Costs (SAMMEC) software are available (http://apps.nccd.cdc.gov/sammec/) for the adult population but omit some short-term costs due to exposure of children (Florence, Adams, & Ayadi, 2007). The estimates of infant delivery costs attributable to maternal smoking contained in SAMMEC had been based on analyses of PRAMS data from 1995 and birth certificate prevalence measures from 1997 (Adams et al., 2002). In this paper we re-estimated the same equations used in the earlier work since our goal was to compare the estimates of smoking attributable expenses (SAE) over time.

The decline in maternal smoking prevalence since 1997 would, independent of other factors, lead to lower smoking attributable infant costs. On the other hand, continued inflation of medical care costs and the availability and/or increased use of

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more expensive technology could increase smoking attributable costs. Declines in maternal smoking also means the composition of maternal smokers has changed (Adams, Melvin, & Raskind-Hood, 2008) and erosion in pre-pregnancy insurance has made it harder to reach them with cessation services (Adams, Gavin, Manning, & Handler, 2005). Updated information on infant's smoking attributable costs can better inform decisions regarding alternative cessation approaches in this time of economic and fiscal crisis.

Earlier Studies

Studies estimating outcomes and costs due to maternal smoking consist of those using an attributable risk approach (Li, Windsor, Lowe, & Goldenberg, 1992; Lightwood, Phibbs, & Glantz, 1999; Marks, Koplan, Hogue, & Dalmat, 1990; D. R. Miller, Villa, Hogue, & Sivapathasundaram, 2001; Oster, Delea, & Colditz, 1988) as well as studies using a multivariate or structural model (Adams et al., 2002; V. P. Miller, Ernst, & Collin, 1999).

The smoking attributable risk approach generally estimates relative risks associated with smoking-related diseases and derives a smoking attributable fraction (SAF) that is then multiplied times total disease-related expenditures to estimate smoking attributable expenditures. Estimates using this approach equaled $267 million in 1983 dollars (Oster et al., 1988) and an estimated $591 million in 1986 dollars (Marks et al., 1990). The latter is higher due, in part, to a higher assumed rate of Neonatal Intensive Care Unit (NICU) admission (50% vs. 42%) for exposed infants and a higher cost per NICU admission even before adjusting to 1986 dollars.

Researchers have also used econometric modeling to estimate smoking attributable costs (Fellows, Trosclair, Adams, & Rivera, 2002; V. P. Miller et al., 1999, 1999). In earlier work (Adams et al., 2002), we used the 1995 Centers for Disease Control (CDC) Pregnancy Risk Assessment Monitoring System (PRAMS) data for 13 states to estimate infant hospitalization costs associated with smoking during pregnancy. This estimate, $366 million or $704 per maternal smoker (Adams et al., 2002; Fellows et al., 2002), actually compares well with more recent studies using the attributable risk approach (Lightwood et al., 1999; D. R. Miller et al., 2001). The Miller study estimated smoking attributable neonatal plus first year infant costs between $1,025 and $1,225 per maternal smoker in 1996 dollars. The Lightwood study estimated smoking attributable neonatal costs at $263 million in 1995 dollars, but these are actual costs to the hospital, and hence, less than total amounts paid for services as are represented in the MCH-SAMMEC (Adams et al., 2002) and Miller study estimates.

Since the primary pathway through which smoking may affect resource use/costs is through lower infant birth weight, it is important to recognize analysis based on models using propensity scoring by Almond, Chay, and Lee (2005). These authors examined the effect of maternal smoking on low birth weight (below 2500 g) among Pennsylvania singleton infants and found that while maternal smoking increased the incidence of low birth weight by 6.4% in their original regression model, it increased the incidence by only 3.5% in their propensity score model. We also found a lower effect of smoking on the percentage of infants born low birth weight in earlier work using PRAMS data and propensity scoring (unpublished). Hence, we tested our models with and without propensity scoring. We present the latter results.

To estimate our models, we used pooled 2001/2002 PRAMS data for 27 states (AL, AK, AR, CO, FL, HI, IL, LA, MD, ME, MI, MN, MT, NC, ND, NE, NM, NJ, NY [Excluding New York City], OH, OK, RI, SC, UT, VT, WA, WV) and more recent data on hospital costs (2004) and maternal smoking (2003). The three steps used in deriving the current estimates are (a) fitting multivariate regression models on the more current PRAMS data, (b) deriving updated measures of the costs of infant nights in the hospital, and (c) extrapolating the models using more current birth certificate data. We discuss each of these in turn.

Data and Statistical Methods

Data

PRAMS is a state-level population-based surveillance system that assesses maternal behaviors, experiences, and insurance coverage before and during a woman's pregnancy and during the early infancy of her child (Gilbert, Shulman, Fischer, & Rogers, 1999; Lipscomb et al., 2000). In all participating PRAMS states, new mothers are randomly selected monthly from birth certificates by stratified systematic sampling with a random start. All states oversample women at risk for adverse pregnancy outcomes; however, stratification variables such as birth weight and race/ethnicity vary among the states. Sampled mothers are sent a self-administered questionnaire two to six months after delivery; nonrespondents are contacted again via telephone. Researchers can only use data from states with a response rate ≥70%; sample sizes range from 1,300 to 3,000 women annually per state. PRAMS data are weighted for sampling design, non-coverage and nonresponse. Specifically, if a state's multivariate analysis indicates certain characteristics (e.g., marital status, education, race) are associated with nonresponse within a sampling strata, the sample probability weight (wtanal) is adjusted by the ratio of sampled/respondents within that category (e.g., marital status, education, race).

Since PRAMS data do not include monetary values for resources used by infants at delivery, we used the 2004 Thomson Reuter's MarketScan claims data for all inpatient services (accommodation, professional, pharmacy, etc) received during a hospital stay. Monetary values on these claims are the dollar amounts paid by individuals/families or their private insurers for covered infants. We used DRG codes (385, 386, 387, 388, 389, 390, 391) to identify a sample of infants born in 2004 as evidenced by their admission and discharge dates in the inpatient services file of these data. Accommodation codes were used to identify those using any NICU services during their delivery hospital stay and, in turn, the number of nights spent in an NICU versus a regular nursery bed.

Statistical Methods

Using these new data, we estimated the regression models used in deriving the 1996 estimates of SAE as described below. These models first use data on demographics, health risks, and risk behaviors to predict whether an infant is admitted to a Neonatal Intensive Care Unit (NICU) and, in turn, their length of stay:

$$\text{Prob}_i(\text{NICU}) = \gamma_1 + \beta_1 X_i + \phi_1 \text{SMOKE}_i + \varepsilon \tag{1}$$

$$(\text{Nights/NICU}) = \gamma_2 + \beta_2 X_i + \phi_2 \text{SMOKE}_i + \varepsilon \tag{2}$$

$$(\text{Nights/Non-NICU}) = \gamma_3 + \beta_3 X_i + \phi_3 \text{SMOKE}_i + \varepsilon \tag{3}$$

Where the X_i is a vector of maternal characteristics known to affect birth outcomes and utilization. This vector included the following independent variables: (a) mother's age (<19, 20–34 [reference], >34 years); (b) race/ethnicity (non-Hispanic White [reference], non-Hispanic Black, Hispanic, other); (c) mother's education (less than high school, high school, some college [reference], graduate school; (d) marital status (single, married [reference]); (e) region (Northeast, Midwest, South, West [reference]); (f) insurance at delivery (private [reference], Medicaid, uninsured); (g) previous live births (none [reference], 1, or more); (h) prenatal care (none, first trimester [reference], second trimester, third trimester); and (i) log of number of drinks pre-pregnancy. Equation 1 was estimated using logistic regression. Separate models were run for Pennsylvania and Washington as alcohol use is not contained on their birth certificates; models were robust across these alternative specifications.

While a log form equation is often used to deal with the skewed nature of these data, recent research (Manning, 1998; Mullahy, 1998) suggests that this approach does not necessarily produce efficient or unbiased estimates. Newer approaches to modeling expenditures or other skewed data include estimating the equation directly as a nonlinear (generalized gamma, in this case) function of the regressions, which results in smaller *SE*s. We used this approach for the second and third equations.

A key statistical issue stems from our reliance on survey data rather than data from a randomized trial. In observational studies, assignment of subjects to the treatment and control groups is not random, and hence, the estimation of the effect of treatment may be biased by the existence of confounding factors. Using the propensity score method can improve estimates tainted by selection bias (Rosenbaum & Rubin, 1983) and as noted by Rubin (2001), this approach is particularly important when estimating smoking attributable expenses (SAEs). In our observational data, mothers who smoke differ from those who do not. Specifically, smokers were younger, less likely to be Black, Hispanic, or other non-White race; had fewer years of schooling; were more likely to have had previous births; and to be Medicaid insured at delivery than nonsmokers (see Appendix). Such differences could bias our estimates of the effect of smoking on ICU use among infants to the extent that omitted variables are correlated with these demographic factors. To address this concern, we estimated our models using propensity score weights for nonsmoking mothers so that the distribution of various observed characteristics, including age, race, and education was similar between our comparison (the nonsmoking population) and treatment (smoking population) groups.

We obtained propensity score weights by following routines described in Schen and Zuckerman (2005). Specifically, we first evaluated the conditional probability of being in the treatment group, given the observed characteristics of each mother (smoker or nonsmoker). This predicted probability, or propensity score, was then used to create adjustment factors to apply to the survey weights for nonsmoking mothers. This factor was derived by (a) arraying the distribution of propensity scores for the treatment group into deciles; (b) finding the share of the comparison group falling into each decile based on their propensity score; and (c) calculating an adjustment factor equal to the ratio of the share of the treatment group to the share of the comparison group in each decile. We then rescaled the factor-adjusted survey weights to keep the sum of these weights equal to our original population.

We found the propensity score reweighing to be effective in mitigating differences in observed characteristics of smokers versus nonsmokers. Comparisons of the means pre and post, the propensity score reweighing are presented in the Appendix. As these data show, after reweighing (matched sample), there are only four remaining categories (college graduate, Midwest, West, and Hispanic) in which smokers and nonsmokers differ significantly. Moreover, differences in the means for maternal smokers versus nonsmokers in the matched sample are less than 1.5% points in these four, as well as all other, categories of the independent variables.

Extrapolation

While we could extrapolate these models using PRAMS data alone, out goal is to derive a national estimate. Hence, we extrapolate by using the 2003 birth certificate data on all births within each state and the coefficients from the models estimated on mother/baby pairs in PRAMS to derive predicted probability of NICU admission and predicted nights for each birth. Since PRAMS does not contain monetary values, we assigned dollars to the additional use of resources implied by NICU admission and length of stay based on amounts paid for infants who used the NICU during their delivery hospitalization from the MarketScan data as described earlier. Specifically, amounts paid for care and nights spent in the NICU versus a regular nursery were identified for all infants. We then estimated:

$$\begin{aligned} s_{\text{NICU}} &= \text{average cost per NICU night;} \\ s^{\text{N}} &= \text{average cost per regular nursery night for infants} \\ &\quad\ \text{ever in the NICU; and} \\ s_{\text{N}} &= \text{average cost per regular nursery night for infants} \\ &\quad\ \text{never in the NICU.} \end{aligned} \tag{4}$$

Infants admitted to an NICU do not necessarily spend their entire stay there. To translate the number of nights into averages, we estimated the proportion (p) of total nights actually spent in an NICU by infants ever admitted to an NICU at .61 from the 2004 MarketScan database. The term ($p \times s_{\text{NICU}} + (1 - p)\, s^{\text{N}}$) may then be interpreted as the average per night cost for infants who are ever admitted to the NICU. We then used 2004 average nightly costs (by region) from the MarketScan data to derive a predicted dollar expense, $\$_i'$, as follows:

$$\begin{aligned} \$_i' = [\{(P_i' \times x_i' b_{\text{ei}}) \times (p \times s_{\text{NICU}} + (1-p)s^{\text{N}})\} \\ + \{((1-P_i') \times x_i' b_{\text{en}}) \times s_{\text{N}}\}] \end{aligned} \tag{5}$$

Where: P_i' = predicted probability of NICU admission for infant $_i$, $x_i'b_{ei}$ = predicted nights given an NICU admission for infant $_i$, and $x_i'b_{en}$ = predicted nights given no NICU admission for infant $_i$.

To extrapolate infants' SAEs and fractions, we derived predicted costs first "as is," based on the mother's actual behavior, and then, "as if" the mother did not smoke (SMOKE = 0) using the coefficients from equations 1–3 above. Intuitively, this is the difference in the expected costs for infants given their actual in utero smoke exposure experience and their expected costs "as if" they were not exposed or their SAEs. The SAE is the denominator in the algebraic expression for the SAF below:

$$\mathrm{SAF} = \frac{\$_i' - \$_I''}{\$_i'} \qquad (6)$$

where i indexes individuals and: $\$_i'$ = the predicted infant costs at delivery hospitalization when the smoking variable(s) have been set to their actual values; $\$_i''$ = the predicted infant costs at delivery hospitalization when the smoking variable(s) have been set to zero.

The expression on the left-hand side of the numerator and in the denominator is the sum of the values from equation (5) over all mothers/infants. The expression on the right-hand side of the numerator is the sum of the values from equation (5)over all mother/infant pairs "as if" no mother smoked. The difference is estimated SAE.

Results

The data in Table 1 show that estimated nightly costs per infant in a regular nursery bed for non-NICU users (column 1) range from $905 in the South to $1,195 in the Western region. For infants ever admitted to an NICU, "NICU users" as noted in column 2, we present mean nightly costs for nights spent in an NICU or regular nursery bed. Their nightly costs when in an NICU bed vary from $3,293 in the South to $3,755 in the Midwest; when in a regular nursery bed, they vary from $2,301 in the West to $2,510 in the Midwest. Once the nightly costs for NICU users are weighted by the proportion of their total nights that these infants actually spend there (.61 noted earlier), the mean nightly costs for NICU users (column 3) range from a low of $2,938 in the West to a high of $3,269 in the Midwest. Thus, the estimated nightly costs for infants ever admitted to the NICU are close to $2,000 higher than those not admitted to an NICU in all regions except in the West, where the difference is approximately $1,700. The *SD*s shown in each cell reflect the markedly skewed distribution of expenditures for infants at delivery and the imprecision inherent in measuring a mean expenditure per infant whether in the NICU or not.

As shown in Table 2, we found no significant relationship of maternal smoking to the odds of admission to an NICU but a positive and significant effect of exposure on the length of stay for infants ever admitted to an NICU. We note that the number of nights used in the equations estimated for infants admitted to the NICU include nights spent in either the NICU or a regular nursery bed. The result in Table 2 indicates that this total number of nights was higher (coefficient = .1322) for infants exposed to maternal smoke versus those not exposed. This increment in nights associated with exposure, coupled with the higher nightly costs for infant users of NICU versus nonusers, leads to higher costs for infants exposed to maternal smoking. These incremental differences drive the estimates of SAEs. By using geographic-based means, we take into account variation across regions in medical practice and costs.

Based on the data for the independent variables for the 3.4 million births in the 2003 natality files, we estimate a total SAE for infants at delivery of $122 million (*CI* = −$29m to $285m) as shown in Table 3 This 2003 SAE estimate

Table 1. Estimated Mean Costs and (*SD*s) per Night for Infants With and Without NICU Admission by Type of Bed and Region in 2004

	Non-NICU users	NICU users by type of bed	NICU users weighted nightly costs
Northeast			
Regular nursery night	$1,083 (±$1,684)	$2,493 (±$6,606)	$3,171 (±$8,699)
NICU nursery night	–	$3,605 (±$10,037)	
Midwest			
Regular nursery night	$1,074 (±$1,990)	$2,510 (±$7,124)	$3,269 (±$9,216)
NICU nursery night	–	$3,755 (±$10,554)	
South			
Regular nursery night	$905 (±$1,602)	$2,385 (±$7,054)	$2,939 (±$8,536)
NICU nursery night	–	$3,293 (±$9.484)	
West			
Regular nursery night	$1,195 (±$2,073)	$2,301 (±$7,035)	$2,938 (±$8,957)
NICU nursery night	–	$3,346 (±$10,186)	

Note. Source: Private sector claims data from the MarketScan Decision Support System maintained at the Centers for Disease Control for research purposes. Data are for 2004.

The dollar value for 1 *SD* plus or minus from the mean is provided in parentheses in each cell. These reflect the highly skewed nature (right tail) of the nightly costs of infants at delivery.

Table 2. Regression Coefficients on Exposure to Prenatal Smoke From Econometric Models[a] of Admission to NICU, Total Length of Stay for Infants Ever Admitted and Not Ever Admitted to NICU

	Effect on odds of NICU admission[b]	Effect on length of stay[c] for infants ever admitted to NICU	Effect on length of stay for infants[c] not ever admitted to NICU
PRAMS 2002/2002 pooled state (27) data unweighted $N = 74{,}986$, weighted $N = 2{,}985{,}392$			
Maternal smoking pre-pregnancy and in third trimester	−0.0882 (−0.2020 to 0.0256)	0.1322* (0.0539 to 0.2105)	0.0011 (−0.0198 to 0.0220)

Note. 95% *CI*s provided in parentheses. PRAMS = Pregnancy Risk Assessment Monitoring System.

[a]Models included controls for: (a) mother's age (<19, 20–34 [reference], >34); (b) race/ethnicity (non-Hispanic White [reference], non-Hispanic Black, Hispanic, other); (c) mother's education (less than high school, high school, some college [reference], graduate school; (d) marital status (single, married [reference]); (e) region (Northeast, Midwest, South, West [reference]); (f) insurance (private [reference], Medicaid, uninsured); (g) previous live births (none [reference], 1, or more); (h) prenatal care (none, first trimester [reference], second trimester, third trimester); and (i) log of number of drinks pre-pregnancy.

[b]Estimated using logit regression model.

[c]Estimated using generalized linear model.

*$p \leq .05$.

represents a large decline in nominal dollars, almost 67%, from the $366 million estimate. The decline in SAE per maternal smoker is around 60%, from $704 in 1996 to $279 (*CI* = −$76 to $653) in 2004. One reason for the decline in total SAE is the declining prevalence of smoking during pregnancy. The prevalence of smoking, as measured by birth certificate data, has declined from 13.4% to 10.7% or about 19%, over the 1997–2003 period.

Subgroup Estimates

The data in Table 4 indicate that the highest prevalence of maternal smoking is in the Midwest (14.3%), while the largest SAE, estimated at $48 million, is attributable to infants exposed to maternal smoke in the South. This is due to the larger number of births occurring in southern states and a somewhat higher difference in the nightly costs of NICU versus non-NICU users in that region. The lowest prevalence of maternal smoking is for mothers in the West (8.7%); the estimated SAE for this region is $23 million. There are also clear differences by race/ethnicity and age. Teens and White non-Hispanic mothers are more likely to smoke during pregnancy, and due to their larger numbers and higher prevalence, White non-Hispanics account for the largest portion of total SAE, around 68% of the total $122 million. Teens have a higher prevalence than other age groups, 15.3% versus only about 7% for mothers aged 35 years and over, but their estimated SAE ($18 million) accounts for only 15% of the total $122 million due to their smaller numbers.

Limitations

Although this updated analysis provides valuable information regarding the potential scope of infant health care costs attributable to mothers' smoking, there are several limitations. First, despite the successful expansion of PRAMS to now include almost 37 states, 1 tribal project, and 1 metropolitan city, it is not a national surveillance system. If the

Table 3. Estimated Smoking Attributable Expense (SAE) Based on National Birth Certificate Data, 1996 and 2004 Dollars (in millions)

	SAEs in 1996 dollars for the 50 states and DC	SAEs in 2004 dollars for the 50 states and DC
Prevalence of reported smoking	13.4%[a]	10.7%[b]
SAF[c]	2.26%	0.46% (−0.11% to 1.06%)
SAE[d]	$366m	$122m (−$29m to $285m)
SAE/maternal smoker[d]	$704	$279 (−$67 to $653)

Note. Confidence intervals for 2004 estimates of SAF, and *SE* derived from 95% *CI* for significant parameters in Table 2.

[a]Prevalence is based on 1997 birth certificate data, except for Indiana, New York, and California. Prevalence for Indiana and New York (upstate) were obtained from Pregnancy Risk Assessment Monitoring System (PRAMS) data; natality files for New York City were combined with PRAMS to provide a state estimate. California smoking prevalence was estimated from the Maternal and Infant Health Assessment survey.

[b]Prevalence is based on 2003 birth certificate data, except for California. California smoking prevalence was estimated from the 2003 MIHA survey.

[c]SAF = Smoking attributable fraction, derived as noted in text.

[d]SAE = Smoking attributable expenditures, derived as noted in text in total and per maternal smoker.

Table 4. Estimated SAE and SAF by Region. Age and Race/Ethnicity, 2004 (dollars in millions)

	Region				Age			Race/Ethnicity			
	Northeast	Midwest	South	West	<20	20–34	≥35	Non-Hispanic White	Non-Hispanic Black	Hispanic	Other
Prevalence	10.1%	14.3%	10.0%	8.7%	15.3%	10.8%	6.8%	14.4%	8.9%	3.0%	6.2%
SAF[a]	0.45% (−0.09% to 1.03%)	0.58% (−0.14% to 1.35%)	0.45% (−0.12% to 1.06%)	0.37%(−0.08% to .85%)	0.58% (−0.15% to 1.36%)	0.46% (−0.12% to 1.07%)	0.37% (−0.07% to 0.85%)	0.59% (−0.16% to 1.38%)	0.50% (−0.08% to 1.13%)	0.14% (−0.02% to 0.31%)	0.28% (−0.06% to 0.64%)
SAE[b]	$20m(−$4m to $46m)	$32m (−$8m to $74m)	$48m (−$13m to $113m)	$23m (−$5m to $52m)	$18m (−$4m to $42m)	$86m(−$21m to $202m)	$18m (−$3m to $41m)	$83m (−$22m to $196m)	$27m (−$5m to $61m)	$8m (−$1m to $17m)	$4m (−$.9m to $10m)

Note. Confidence intervals for 2004 estimates of SAF and SAE derived from 95% *CI* for significant parameters in Table 2.
[a]SAF = smoking attributable fraction, derived as noted in text.
[b]SAE = smoking attributable expenditures, derived as noted in text in total and per maternal smoker.

inclusion of other states in the regression models would lead to significantly different coefficients, our estimates are biased. We note that PRAMS study states are geographically dispersed and the births included in the regression analysis account for approximately 40% of the national total (just over 3 million). Furthermore, when we examined the characteristics of mothers in our study states versus the nation overall, we found that there were only two instances (age and race) where the distribution of mothers' characteristics differed from the national distribution by more than 1%.

A key limitation is that our measure of maternal smoking is based on self-report. It is well known that there is underreporting of smoking which would bias our effects downward, and yet, the PRAMS measure has the advantage of reflecting that a mother reported smoking both pre-pregnancy and in her third trimester which has the strongest effect on birth weight (USDHHS, 2004). In recognition of the underreporting, researchers have developed a measure of smoking that combines the PRAMS and birth certificate data (Allen, Dietz, Tong, England, & Prince, 2008), which results in a 16% higher estimate than one derived from PRAMS alone (Tong, Jones, Dietz, D'Angelo & Bombard, 2009). We used the data to derive this "combined" measure and reestimated our models; estimated coefficients were robust. We are not able to improve further upon this measure and recognize this as a limitation.

Even this combined measure, however, omits the effect of secondhand smoke exposure of mothers who do not smoke but whose partners or other members of the household do. This measure is not available in the PRAMS and, hence, remains a limitation. We note that the surgeon general reports this type of secondhand exposure has having a small effect on infant birth weight (USDHHS, 2004). However, the exposure of nonsmoking women of reproductive age could be as high as 30% (USDHHS, 2006b). While the newer birth certificate form includes a better measure of maternal smoking, it does not address secondhand smoke and only a small number of states have adopted the new form. PRAMS remains an important source of data on maternal smoking and birth outcomes.

Our findings are also limited in that they omit additional costs related to spontaneous abortion, ectopic pregnancy, or other maternal conditions shown to be related to smoking during pregnancy. They also do not include infant health care costs that occur after the delivery hospitalization, such as additional readmissions in the first year of life, or costs related to secondhand smoke exposure of infants and children. Comparing the D. R. Miller et al. (2001) (2001) estimates for neonatal plus first year infant costs attributable to smoking to our 1996 neonatal estimates indicates the first year costs add between $312 and $521 per maternal smoker. Florence et al. (2007) estimated smoking attributable costs from secondhand exposure of children through age 12 at $52 per exposed child and a national total as high as $660 million.

Our use of private sector claims data to estimate the nightly costs of an infants may overestimate the costs for Medicaid-insured women as these reimbursement rates are lower (Zuckerman, McFeeters, Cunningham, & Nichols, 2004). This concern is balanced somewhat by the fact that Medicaid serves more women with high-risk pregnancies likely in need of more services. Since nightly costs reflect both the number/intensity of services and reimbursement per service, the nightly costs of Medicaid infants whether in the NICU or not may be comparable to and/or higher than those of privately insured infants (Adams, Ayadi, Melvin, & Rivera, 2004; Adams, Bronstein, & Becker, 2001).

We are also not able to shed much light on our finding that the pathway through which exposure affects resource use appears to be through longer stays for infants once admitted to an NICU rather than through an increased probability of NICU admission. We do note that there was a slight change in the question regarding NICU admission in the PRAMS data. Earlier, PRAMS asked about admission to an NICU "or premature nursery," whereas currently it asks about NICU admission. PRAMS staff did not view this as a major change, and the overall percentage admitted to an NICU as estimated by PRAMS data remained stable. Moreover, this change does not explain why we see the unexpected insignificant relationship of smoking to NICU admission in the current data.

Finally, changes over time in the estimates of smoking attributable expenditures at delivery for infants should be interpreted with caution. The 2004 estimates are based on a larger sample of PRAMS states and births and also include an additional independent variable, Hispanic ethnicity, in the models. Since the different mix of states could alter the analysis, we retested models using only that subset of states available in both the earlier and current period. Results were stable. Moreover, a positive association of smoking with NICU admission was found for some subgroups—those very preterm (greater than 20 but less than 32 weeks of gestation) and born to moderate (20–29 cigarettes/day) or heavy (30–40 cigarettes/day) prenatal smokers. This may be evidence that the need for NICU admission among exposed infants has become more focused among the smallest babies as neonatal medical technology has advanced.

Discussion

The data reported here indicated that total health care costs attributable to maternal smoking for infants at delivery declined 67% from the 1996 to 2004 estimate. The corresponding decline in the prevalence of maternal smoking over this period puts the United States closer to its Healthy People 2010 goal of 1%, but rates appear to have hit a plateau and still vary markedly across states (CDC, Department of Health and Human Services, 2009). The decline does indicate that success in reducing health risk behaviors can be accompanied by lower SAEs even as overall health care costs rise. The need to maintain this success and the potential of further savings should spur continued public health efforts to reduce maternal smoking and its related costs, which often fall on the public sector and taxpayer.

Changes in the magnitude of the SAE estimates reflect the combined effect of the changed association of smoking and NICU use, increased medical costs, and declines in maternal smoking prevalence over time. Estimated SAE decreased over time, even though medical care inflation grew significantly from 1996 to 2004; the hospital component of the medical Consumer Price Index grew by 35.8% or about 4.5% annually. Estimated delivery costs for all infants in our sample, however, grew in excess of inflation at 62%, from $16.1 billion in 1996 to $26.3 billion in 2004 and per birth, from $4,169 to $6,430, or almost 7% annually. Thus, while estimated expenses at delivery for all infants were growing along with inflation, the net effect of the several changes affecting smoking attributable costs was to lower estimated total, and per maternal smoker, SAE.

Both the SAE estimates reported here and estimates included in the CDC software were based on PRAMS and birth certificate data and the same set of equations as used in deriving the 1996 estimates. The CDC software is not currently based on the propensity scoring results. The estimate in the software, $154 million, is within the range of estimates found in analysis of the Medical Expenditure Panel Survey data for 2000–2003 (Florence et al., 2007), which reported a national estimate of infant delivery costs attributable to smoke exposure between $150 and $230 million. Our current estimate of $122 million falls outside this range. Both estimates, however, are consistent with evidence that neonatology practice has changed over time, such as the use of cost-effective surfactant therapy for infants with respiratory conditions (Phibbs et al., 1993; Richardson et al., 1998; Schwartz, Luby, Scanlon, & Kellogg, 1994) and more aggressive use of all respiratory support modalities (Richardson et al., 1998). There is also evidence of a secular change in the distribution of NICU admissions and length of stay by birth weight (Tatad & Frayer, 2003). Although the latter study also notes improved antenatal care, it is restricted to one large medical center.

Other secular changes such as the increased use of (capitated) Medicaid-managed care over the latter 1990s could reduce NICU admissions among Medicaid women, more often smokers (Stankaitis, Brill, & Walker, 2005). Finally, since maternal smoking is more likely reflected in term, low birth weight versus very preterm, exposed infants may be less likely to be taken care of in the NICU currently. Indeed, a recent study hypothesized that due to requirements that all hospitals be smoke free, infants of smokers would have shorter stays; their findings confirmed this for over 400,000 singleton, "well" newborns ≥35 weeks of gestation in one state (Paul et al., 2009). More studies at the national level are needed to better understand trends in NICU admission, infant and mother's length of stay, and the role that maternal smoking plays.

The estimated smoking-related infant delivery costs presented here can be used not only for advocacy purposes but also for analyzing the cost-effectiveness of interventions aimed at pregnant women (Fiore et al., 2000; Melvin, Dolan-Mullen, Windsor, Whiteside, & Goldenberg, 2000). Information is needed, however, on how much more these interventions cost. One study of the incremental costs for the five A's smoking cessation intervention in three practice settings serving pregnant women, estimated these between $24 and $34 per women (Ayadi et al., 2006). The lower SAE per smoker estimated here means that only lower-cost interventions would tend to be cost saving if based on delivery costs alone.

We stress again that our estimates of costs at delivery may be underestimated due to the data and statistical issues noted earlier. They are clearly a subset of total costs attributable to maternal smoking since we omit costs for infants in their first year of life, children exposed postpartum, and conditions that affect the mother's long-term health. We also stress that the variation around our estimate of smoking attributable expenditures using propensity scoring indicates statistical insignificance. There is inherent uncertainty in deriving such cost estimates since high-cost births/deliveries occur with low probability and are difficult to predict. There is also significant geographic variation in physician and hospital practices with respect to NICU admission and availability/use of advanced technology, and we can only estimate mean infant costs at the regional level. Yet, the bulk of the confidence interval around our estimate of SAE indicates positive smoking attributable costs. To the extent that these are related to preventable adverse outcomes at birth, they are highly relevant to the public's health.

State-specific estimates of SAEs could help states explore potential cost savings from smoking cessation interventions such as the five A's and other policies (e.g., excise taxes, regulations on clean air, Medicaid reimbursement policies) that can reduce smoking prevalence among pregnant women (Ringel & Evans, 2001; Petersen, Garrett, Melvin, & Hartmann, 2006). Given the disproportionate burden of smoking attributable costs on the Medicaid program (Adams et al., 2004), these and other evidence-based polices and interventions (e.g., promotion of state telephone-based quit lines) could help reduce the prevalence of maternal smoking and relapse rates as well as reduce secondhand smoke exposure of new infants and children. Quitting will also help women cope with their own health and well-being as well as lower their anticipated health care expenses. These potential additional cost savings need to be considered as policy makers and providers count the costs and benefits of smoking cessation interventions.

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Declaration of Interest

None declared.

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Appendix: Comparison of Mean Difference Test for Smokers and Nonsmokers, Original Versus Matched Sample After Propensity Scoring

	Original sample			Matched sample		
	Smoker	Nonsmoker	Difference	Smoker	Nonsmoker	Difference
Insurance at delivery						
Private	35.15%	60.12%	−24.97%*	35.15%	35.38%	−0.23%
Medicaid	60.47%	35.34%	25.13%*	60.47%	59.93%	0.54%
Uninsured	4.38%	4.54%	−0.16%	4.38%	4.69%	−0.31%
Prenatal care						
First trimester	77.94%	84.80%	−6.86%*	77.94%	78.29%	−0.34%
Second trimester	17.27%	12.48%	4.79%*	17.27%	17.07%	0.21%
Third trimester	3.30%	2.12%	1.18%*	3.30%	3.28%	0.02%
No prenatal care	1.48%	0.59%	0.89%*	1.48%	1.37%	0.11%
Age						
<19	16.10%	10.63%	5.47%*	16.10%	16.23%	−0.13%
19–34	73.86%	75.59%	−1.73%*	73.86%	73.65%	0.21%
>34	10.04%	13.78%	−3.74%*	10.04%	10.12%	−0.08%
Race						
Non-Hispanic White	81.38%	61.59%	19.79%*	81.38%	80.54%	0.84%
Black	10.67%	17.49%	−6.82%*	10.67%	10.37%	0.30%
Hispanic	3.92%	14.93%	−11.01%*	3.92%	4.82%	−0.90%*
Other	4.04%	5.99%	−1.96%*	4.04%	4.27%	−0.23%
Marital status						
Single	53.21%	30.41%	22.80%*	53.21%	53.66%	−0.46%
Education						
<High school	32.43%	16.51%	15.92%*	32.43%	30.76%	1.67%
High school graduate	43.83%	30.15%	13.68%*	43.83%	44.62%	−0.78%
Some college	17.95%	22.83%	−4.89%*	17.95%	17.37%	0.58%
College graduate+	5.80%	30.51%	−24.71%*	5.80%	7.26%	−1.46%*
Region						
Northwest	12.10%	11.40%	0.70%*	12.10%	12.40%	−0.30%
Midwest	35.07%	29.58%	5.49%*	35.07%	34.02%	1.05%*
South	41.21%	43.08%	−1.87%*	41.21%	41.43%	−0.22%
West	11.62%	15.94%	−4.32%*	11.62%	12.15%	−0.53%*
Other						
Prior live births	1.16	0.98	0.18*	1.16	1.13	0.02
Mom drinking	0.0011	0.0010	0.0001*	0.0011	0.0011	0.00

Note. *Significant at $p < .05$.

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