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Prenatal care effectiveness and utilization in Brazil

George L Wehby,[1]* Jeffrey C Murray,[2] Eduardo E Castilla,[3] Jorge S Lopez-Camelo[4] and Robert L Ohsfeldt[5]

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The impact of prenatal care use on birth outcomes has been understudied in South American countries. This study assessed the effects of various measures of prenatal care use on birth weight (BW) and gestational age outcomes using samples of infants born without and with common birth defects from Brazil, and evaluated the demand for prenatal care. Prenatal visits improved BW in the group without birth defects through increasing both fetal growth rate and gestational age, but prenatal care visits had an insignificant effect on BW in the group with birth defects when adjusting for gestational age. Prenatal care delay had no effects on BW in both infant groups but increased preterm birth risk in the group without birth defects. Inadequate care versus intermediate care also increased LBW risk in the group without birth effects. Quantile regression analyses revealed that prenatal care visits had larger effects at low compared with high BW quantiles. Several other prenatal factors and covariates such as multivitamin use and number of previous live births had significant effects on the studied outcomes. The number of prenatal care visits was significantly affected by several maternal health and fertility indicators. Significant geographic differences in utilization were observed as well. The study suggests that more frequent use of prenatal care can increase BW significantly in Brazil, especially among pregnancies that are uncomplicated with birth defects but that are at high risk for low birth weight. Further research is needed to understand the effects of prenatal care use for pregnancies that are complicated with birth defects.

Keywords Prenatal care, low birth weight, preterm birth, quantile regression, birth outcomes, infant health, Brazil

[1] MPH, PhD, Assistant Professor, Dept of Health Management and Policy, College of Public Health, University of Iowa, Iowa City, IA, USA.
[2] MD, Professor, Department of Pediatrics, College of Medicine, University of Iowa, Iowa City, IA, USA.
[3] MD, PhD, Professor, ECLAMC (Latin American Collaborative Study of Congenital Malformations) at CEMIC, Buenos Aires, Argentina, and ECLAMC at Instituto Oswaldo Cruz, Rio de Janeiro, Brazil.
[4] PhD, Professor, ECLAMC at Imbice, La Plata, Argentina.
[5] PhD, Professor, Health Policy & Management, School of Rural Public Health, Texas A&M Health Science Center, College Station, TX, USA.
* Corresponding author. Assistant Professor, Dept of Health Management and Policy, University of Iowa, E204, GH, Iowa City, IA 52242, USA. Tel: +1–319–384–5133. Fax: +1–319–384–5125. E-mail: george-wehby@uiowa.edu

KEY MESSAGES

- Improved utilization of prenatal care in Brazil may have large benefits for birth weight, especially among pregnancies that are uncomplicated with birth defects but are at high risk for low birth weight.
- Improving the standard of prenatal care by increasing the number of recommended prenatal visits and increasing women's awareness of the benefits of prenatal care are key for improving utilization.

Introduction

Birth outcomes including low birth weight (LBW) and preterm birth are frequent adverse outcomes that contribute significantly to infant mortality and delayed child development. LBW occurs among 16% and 7% of births in developing and developed countries, respectively (Lawn *et al*. 2005). In Brazil, the largest country in South America, an 11% LBW rate was reported in 1994 (Goldani *et al*. 2004a). The LBW rate has increased by about 49% between 1978–79 and 1994 in the Southeastern region (Goldani *et al*. 2004a) and by 17% between 1982 and 2004 in the city of Pelotas in the South (Barros *et al*. 2005). Preterm birth rates have also increased in Brazil over the past two decades, by more than 150% (from a 6.3% rate) in Pelotas City between 1982 and 2004 (Barros *et al*. 2005). Large declines in specific neonatal and infant mortality rates specific to gestational age and birth weight have been reported over this period as well (Goldani *et al*. 2004b; Barros *et al*. 2005); neonatal mortality decreased by about 40 and 70% among premature and LBW infants, respectively, between 1982 and 2004. LBW and preterm birth rates have also increased in the United States (US) by about 28 and 16%, respectively, over the past two decades (Arias *et al*. 2003).

The increase in incidence rates and improved survival of affected births could increase the prevalence of developmental disabilities, particularly among very LBW and preterm babies in less developed settings. Child disability exerts a large burden on the individual and family quality of life and economic wellbeing, with larger impacts expected in less developed countries. LBW and preterm birth have negative effects on development and cognitive/neurobehavioral outcomes during infancy, childhood and adolescence (e.g. Mervis *et al*. 1995; Schendel *et al*. 1997; Saigal *et al*. 2001; Wolf *et al*. 2001; Boardman *et al*. 2002; Anderson and Doyle 2003). Limitations include visual impairments, learning disabilities and challenges in schooling performance, hyperactivity and lower achievement on other developmental and behavioral aspects. Preterm babies are also at an increased risk for several early onset medical problems (some with potentially lifelong impacts) including respiratory distress syndrome, apnea, intraventricular haemorrhage, patent ductus arteriosis, anaemia, chronic lung disease and infections (March of Dimes 2007). LBW and preterm birth also increase healthcare utilization and costs; preterm births have about 10 times higher medical costs in the first year of life than full-term births (March of Dimes 2006).

Given the importance of these birth outcomes, identifying their determinants, particularly those that are amenable to changes through health policies, becomes highly relevant for improving infant and child health. Prenatal care use is of particular interest given the general perception that it has a positive impact on overall fetal and maternal health and that it can be targeted by health policy interventions. Yet there has been limited research into the effectiveness of prenatal care utilization and other potentially relevant prenatal health behaviors and factors in improving birth outcomes in less developed settings. Most well-designed observational studies have focused on US data and have generally found modest effects on birth outcomes (focusing mostly on birth weight) (e.g. Rosenzweig and Schultz 1982, 1983, 1988; Joyce 1985, 1987, 1994; Conway and Deb 2005; Evans and Lien 2005). Most studies have also ignored the potential heterogeneity in effects of prenatal care by biologic, environmental and socio-economic risks (referred to hereafter as fetal health risks) and focused on estimating average effects.[1]

This study evaluates the effectiveness of prenatal care utilization in improving birth weight and gestational age outcomes among samples of infants born with and without selected birth defects in Brazil. The analyses by birth defect status evaluate the existence of heterogeneity in prenatal care effectiveness by genetic risks that cannot be measured directly but are expected to be more common in the group with birth defects. The selected birth defects occur early on in pregnancy and are largely affected by genetic risk factors, allowing the birth defect status to be used as an indicator for higher genetic risks that is exogenous to prenatal care. We also apply quantile regression to further evaluate the heterogeneity of prenatal care effectiveness within the two infant groups. Since pregnancies with higher fetal health risks (as defined above) are expected to have births on the left side of the birth weight distribution, estimating the effects of prenatal care and other prenatal factors on birth weight quantiles (percentiles) provides an approach to evaluate heterogeneity in effectiveness by these risks, many of which cannot be directly measured using the typically available data. The study also evaluates the demand for prenatal care and has important health policy implications for improving birth outcomes in Brazil.

Methods

Study sample

The study sample included 1716 infants without birth defects and 1695 infants with one or more of the following birth defects: cleft lip and/or palate, neural tube defects, trisomy 21, congenital heart disease and polydactyly, which represent the five most common birth defects. The infants were born in 18 hospitals in Brazil between 1995 and 2002 (inclusive) and were recruited by the Latin American Collaborative Study of Congenital Malformations (ECLAMC) which is a WHO Collaborating Center involved in surveillance and research of birth defects in South America (Castilla and Orioli 2004). ECLAMC is affiliated with a large network of health professionals (mostly pediatricians) who identify and enrol each newborn in their hospitals with a congenital anomaly as well as control newborns born without birth defects and matched one-to-one by sex, hospital and date of birth.[2] Birth record data are collected on each birth through an interview with the mother and abstraction from the hospital records. The study sample was limited to mothers who are 20 years or older given the endogenous selection of education and other characteristics at younger ages, and to singleton live births with birth weights between 500 and 6000 grams and gestational ages between 19.5 and 46.5 weeks to avoid recording errors.[3]

Measures of prenatal care and birth outcomes

The measures of prenatal care use that were evaluated in this study included prenatal care delay, measured as the time in weeks between pregnancy occurrence and initiation of prenatal care, the number of prenatal care visits, and prenatal care inadequacy and adequacy measured with the Kessner index (Kessner 1973). It is important to consider these alternative measures given that they can have different effects on birth outcomes and given that they have different advantages and disadvantages compared with each other. For instance, prenatal care delay is less reversely affected by gestational age compared with the number of prenatal care visits and the Kessner indicators.[4] Also, adequacy indices of prenatal care such as the Kessner index or the adequacy of prenatal care utilization (APNCU) index (Kotelchuck 1994) that incorporate gestational age, prenatal care delay and number of visits may have a bias by construction when estimating their effects on birth outcomes (Kotelchuck 1994; Koroukian and Rimm 2002; Kotelchuck 2003). One conceptual limitation in using these indices is that they are based on standards that may not apply to the study setting and they already imply an effective or appropriate level of prenatal care use.[5]

The study outcome measures included binary indicators (0, 1) of LBW (< 2500 grams) and preterm birth (<37 weeks of gestation) as well as continuous birth weight (BW) in grams. Given that BW increases with gestational age and fetal growth rate, alternative models for BW that adjust for gestational age were also studied.

The effects of the three measures of prenatal care use on the BW outcomes were assessed. Only the effects of prenatal care delay on preterm birth were estimated due to the reverse effects of gestational age on the other prenatal care measures.

Birth outcome function

The birth outcomes were modelled as a function of prenatal care utilization and other potentially relevant prenatal health behaviors and factors as well as other characteristics that are expected to affect birth outcomes. These included indicators for use of multivitamins during pregnancy, tetanus and varicella immunization in the first trimester[6] and occurrence of trauma and physical shocks in the first trimester.[7] Also included were indicators for maternal health and fertility characteristics (occurrence of acute and chronic illnesses, occurrence of vaginal bleeding in first trimester, difficulty in conception and numbers of previous live births and miscarriages/stillbirths), family genetic risks (measured by whether there are any family relatives who have one of the studied birth defects), parental education and employment, infant ancestry and sex, pregnancy year and state of birth (in order to capture time and area differences in the birth outcomes).

The LBW and preterm birth outcome functions were estimated by probit regression. The BW (in gm) outcome function was estimated with ordinary least squares (OLS). Robust standard errors were estimated for the probit and OLS models (White 1980).

Quantile regression was used to estimate the effects of prenatal care use and the other included covariates on BW quantiles (Koenker and Bassett 1978; Koenker and Hallock 2001). The standard errors of the quantile regression coefficients were estimated by bootstrap with 200 replications for each estimated quantile regression model.

One analytical issue that complicates the estimation of treatment effectiveness using observational studies is treatment self-selection. Previous econometric studies of prenatal care effectiveness have generally found evidence of adverse self-selection into prenatal care (e.g. Rosenzweig and Schultz 1982, 1983, 1988; Rous *et al*. 2004), with women at higher risks for adverse birth outcomes utilizing more prenatal care. When unaccounted for, this is expected to result in underestimation of prenatal care effectiveness.

One tool that has been commonly employed to handle self-selection is instrumental variable (IV) analysis, which would utilize variables (instruments) that affect prenatal care (such as distance to prenatal care clinics, price of prenatal care, or access to insurance) but are otherwise thought to have no effects on the studied birth outcomes (i.e. no direct effects or indirect effects through unobserved variables). The instruments therefore are required to be 'exogenous', i.e. not related to unmeasured variables that are also related to the birth outcomes.

Unfortunately, we had no access in this study to good instruments that would satisfy the IV assumptions. We tried to overcome the self-selection problem by using a very well specified regression model that includes several indicators of variables that might lead to adverse self-selection (including maternal health, fertility history and family genetic risks) and by including area-fixed effects, which are expected to account for any differences in health risks that vary between states. As discussed below, the effectiveness of prenatal care (especially prenatal visits) was generally underestimated when unadjusted for the model covariates, providing evidence that some adverse self-selection was accounted for. However, given that adverse self-selection is unlikely to be fully accounted for through direct adjustment of observable covariates (due to the role of unobservable or unmeasured characteristics such as history of LBW in the family or other unmeasured pregnancy risks), we treat the obtained estimates as lower-bound estimates of prenatal care effectiveness.

Prenatal care demand

In addition to evaluating the effectiveness of prenatal care, we also studied the demand for prenatal care visits as the prenatal care use measure that showed consistently significant effects on the BW outcomes, as described below in detail. The number of prenatal care visits was studied as a function of health risk indicators (which reflect health needs and predisposing risks), enabling characteristics and other potentially relevant determinants. The health risk indicators included family genetic risks (measured by family history of the study birth defects), indicators for maternal acute and chronic illnesses and vaginal bleeding in the first trimester, fertility indicators including self-reported difficulty in conception and numbers of previous live births and miscarriages/stillbirths, and maternal age. The enabling characteristics included maternal and father's schooling and employment status.[8] Indicators for year of pregnancy were included to capture time changes in utilization. Infant ancestry was included in order to evaluate disparities by ethnicity. Indicators for the state of birth were included to account for fixed-area effects on utilization due, for instance, to differences in availability of health care, supplemental health insurance and concentration of prenatal care providers.[9]

Given that the number of prenatal care visits is a count variable, the demand function was estimated by a negative binomial regression with robust estimation of the coefficient standard errors.[10] We estimated separate and pooled functions for the samples with and without birth defects to evaluate differences by birth defect status. Table 1 reports a descriptive summary of the study variables.

Table 1 Description of study variables

Variable name	Definition	Mean (Std Dev) or %	
		Infants without birth defects ($N=1716$)	Infants with birth defects ($N=1695$)
Low birth weight	Indicator (0,1) for low birth weight (<2500 grams) (%)	11.0	24.5
Birth weight	Birth weight in grams	3164.1 (596.0)	2931.1 (762.1)
Premature	Indicator (0,1) for gestational age <37 weeks (%)	15.9	24.4
Weeks	Pregnancy weeks elapsed prior to initiating prenatal care	13.5 (8.1)	13.7 (8.4)
Visits	Number of prenatal care visits	7.2 (3.1)	7.3 (3.2)
Inadequate[a]	Indicator (0,1) for inadequate prenatal care based on the Kessner Index (%)	15.2	16.4
Adequate[a]	Indicator (0,1) for adequate prenatal care based on the Kessner Index (%)	27.1	26.5
Multivitamin	Indicator (0,1) for multivitamin use during pregnancy (%)	14.0	14.4
Tetanus	Indicator (0,1) for tetanus immunization in 1st trimester (%)	7.7	5.6
Varicella	Indicator (0,1) for varicella immunization in 1st trimester (%)	3.0	3.2
Physical shocks	Indicator (0,1) for maternal exposure to physical shocks in 1st trimester (%)	5.3	6.9
Birth defect history	Indicator (0,1) for reporting any relatives to the child with the studied birth defects (%)	6.1	22.7
Difficulty in conception	Indicator (0,1) for reporting any difficulty in conception (%)	12.2	12.2
Acute maternal illness	Indicator (0,1) for any acute illnesses during pregnancy (%)	47.8	50.7
Chronic maternal illness	Indicator (0,1) for any chronic illnesses during pregnancy (%)	17.2	19.7
First trimester bleeding	Indicator (0,1) for vaginal bleeding in 1st trimester (%)	8.1	8.7
Live births	Number of previous live births	1.3 (1.5)	1.5 (1.7)
Miscarriages/stillbirths	Number of previous miscarriages and stillbirths	0.3 (0.7)	0.3 (0.7)
Maternal age (25–34 years)[b]	Indicator (0,1) for maternal age between 25 and 34 years inclusive (%)	48.7	47.2
Maternal age (≥35 years)[b]	Indicator (0,1) for maternal age of 35 years or older (%)	14.3	21.7
Maternal education–primary[c]	Indicator (0,1) for completing primary school (%)	14.9	15.5
Maternal education–secondary[c]	Indicator (0,1) for attending secondary school (%)	31.4	30.7
Maternal education–university[c]	Indicator (0,1) for attending university (%)	9.3	8.6
Father's education–primary[c]	Indicator (0,1) for completing primary school (%)	19.5	18.3
Father's education–secondary[c]	Indicator (0,1) for attending secondary school (%)	28.8	28.0
Father's education–university[c]	Indicator (0,1) for attending university (%)	7.5	7.8
Maternal employment	Indicator (0,1) for maternal employment status (%)	43.2	44.6
Father's employment	Indicator (0,1) for father's employment status (%)	95.3	94.9
Native ancestry	Indicator (0,1) for Native ancestry (%)	52.9	53.6
African ancestry	Indicator (0,1) for African ancestry (%)	41.0	43.4
European Latin ancestry	Indicator (0,1) for Latin European ancestry (%)	58.2	59.6
European non-Latin ancestry	Indicator (0,1) for non-Latin European ancestry (%)	19.4	17.0

(continued)

Table 1 Continued

Variable name	Definition	Mean (Std Dev) or %	
		Infants without birth defects ($N = 1716$)	Infants with birth defects ($N = 1695$)
Other ancestry	Indicator (0,1) for other ancestry (%)	3.1	2.2
Male	Indicator (0,1) for a male sampled subject (%)	51.3	52.7
Pregnancy year 95[d]	Indicator (0,1) for pregnancy in 1995 (%)	8.9	9.0
Pregnancy year 96[d]	Indicator (0,1) for pregnancy in 1996 (%)	10.7	9.5
Pregnancy year 97[d]	Indicator (0,1) for pregnancy in 1997 (%)	9.5	10.1
Pregnancy year 98[d]	Indicator (0,1) for pregnancy in 1998 (%)	12.3	12.3
Pregnancy year 99[d]	Indicator (0,1) for pregnancy in 1999 (%)	14.3	15.5
Pregnancy year 00[d]	Indicator (0,1) for pregnancy in 2000 (%)	16.0	15.6
Pregnancy year 01[d]	Indicator (0,1) for pregnancy in 2001 (%)	18.4	18.5
Pregnancy year 02[d]	Indicator (0,1) for pregnancy in 2002 (%)	4.0	4.2
Minas Gerais[e]	Indicator (0,1) for a sampled birth in the state of Minas Gerais (%)	14.9	15.8
Paraiba[e]	Indicator (0,1) for a sampled birth in the state of Paraiba (%)	3.4	3.7
Rio Grande do Sul[e]	Indicator (0,1) for a sampled birth in the state of Rio Grande do Sul (%)	25.9	26.0
Santa Catarina[e]	Indicator (0,1) for a sampled birth in the state of Santa Catarina (%)	21.4	21.2

Note: Standard Deviations are listed in parentheses.
[a]Omitted category is intermediate care.
[b]Omitted category is age ≤24 years.
[c]Omitted category is less than completed primary school (including not attending school).
[d]Omitted category is year 1994.
[e]Omitted category is the state of Sao Paulo.

Results

Effects of prenatal care use on LBW and preterm birth

Table 2 reports the marginal probability effects (ME) of prenatal care delay, number of prenatal visits and inadequate and adequate care Kessner measures on LBW, and the ME of prenatal care delay on preterm birth, both unadjusted and adjusted for the model covariates. For both groups of infants without and with birth defects, prenatal care delay had no significant effects on LBW, but it increased preterm birth risk (or probability) by about 0.003 in the group without birth defects. No significant effect of prenatal care delay on preterm birth was observed in the group with birth defects.

Number of prenatal visits had significant and comparable effects on LBW in the two infants groups, decreasing LBW risk by about 0.013–0.015 per visit. Inadequate care (versus intermediate care) increased LBW risk significantly by about 0.06 in the group without birth defects, but had a statistically insignificant effect in the group with birth defects. On the other hand, adequate care (versus intermediate care) had an insignificant effect in the group without birth defects, but increased LBW risk by about 0.06 in the group with birth defects. In both infant groups, a positive bias was suggested in the unadjusted effects of prenatal care visits and adequate care on LBW, and a negative bias in the unadjusted effects of inadequate care. A negative bias was also suggested in the unadjusted effects of prenatal care delay on preterm birth in the group without birth defects.

Table 2 Marginal probability effects of the prenatal care use indicators on low birth weight (LBW) and preterm birth

Model	Group without birth defects ME (SE)	Group with birth defects ME (SE)
LBW (birth weight <2500 grams)		
Prenatal care delay:		
Unadjusted	0.0005 (0.0009)	0.0006 (0.0013)
Adjusted	0.0002 (0.0009)	0.0012 (0.0014)
Prenatal care visits:		
Unadjusted	−0.0098*** (0.0028)	−0.0096*** (0.0036)
Adjusted	−0.0131*** (0.0027)	−0.0155*** (0.0039)
Inadequate care:		
Unadjusted	0.0506** (0.025)	0.0413 (0.031)
Adjusted	0.0591** (0.0255)	0.0533 (0.0325)
Adequate care:		
Unadjusted	0.0043 (0.0183)	0.0667** (0.026)
Adjusted	−0.0091 (0.0166)	0.0579** (0.0267)
Preterm birth (gestation <37 weeks)		
Prenatal care delay:		
Unadjusted	0.0021* (0.0011)	0.0011 (0.0013)
Adjusted	0.0028** (0.0011)	0.0007 (0.0014)

Notes: Marginal effects (ME) of the prenatal care use indicators on outcome probabilities were estimated holding model covariates at their means. Standard errors (SE) of marginal effects are listed in parentheses. ME were estimated alternatively as unadjusted and adjusted for model covariates.
*, ** and *** indicate significant effects at $P < 0.1$, $P < 0.05$ and $P < 0.01$, respectively.

Table 3 Effects of prenatal care utilization on birth weight

Model	Quantile					Mean effect
	0.1	0.25	0.5	0.75	0.9	
Infants without birth defects						
Prenatal care delay in weeks:						
Unadjusted	−3.5 (4.1)	−3.0 (3.4)	0.0 (2.3)	−0.7 (2.5)	0.6 (2.6)	−1.0 (1.8)
Adjusted	−0.6 (3.7)	0.3 (2.3)	1.9 (1.6)	1.9 (2.3)	2.3 (2.5)	−0.1 (1.9)
Prenatal care visits:						
Unadjusted	37.9*** (10.0)	28.3*** (7.2)	19.3*** (4.0)	11.5** (4.4)	10.0 (8.2)	24.9*** (5.0)
Adjusted	59.0*** (13.4)	44.6*** (6.7)	24.2*** (6.3)	22.9*** (7.7)	13.4** (5.8)	34.2*** (5.6)
Inadequate care:						
Unadjusted	−290.0*** (60.4)	−165.0***(38.7)	−155.0*** (39.7)	−150.0*** (45.4)	−30.0 (84.4)	−140.3*** (42.6)
Adjusted	−185.6 (132)	−125.6** (59.2)	−136.2** (58.5)	−142.3*** (42.8)	−128.7 (80.3)	−153.9*** (43.8)
Adequate care:						
Unadjusted	−10.0 (57.6)	30.0 (50.9)	−10.0 (32.4)	−70.0* (40.2)	−30.0 (52.8)	−27.3 (33.4)
Adjusted	15.4 (65.3)	90.9* (54.8)	−4.0 (35.8)	−77.1 (47.4)	−62.5 (46.5)	−6.4 (33.4)
Infants with birth defects						
Prenatal care delay in weeks:						
Unadjusted	3.1 (5.6)	−3.3 (6.0)	−5.5** (2.6)	−3.4 (2.3)	−3.0 (2.4)	−2.7 (2.2)
Adjusted	0.3 (5.3)	−3.3 (3.9)	−3.0 (2.2)	−2.9 (3.0)	−4.7 (3.0)	−2.6 (2.4)
Prenatal care visits:						
Unadjusted	43.9*** (12.8)	27.1*** (8.0)	13.8*** (4.5)	15.7** (8.0)	18.0* (9.5)	25.3*** (5.9)
Adjusted	59.7*** (12.1)	31.5*** (8.4)	16.8** (7.0)	20.0*** (6.2)	17.8* (9.9)	31.7*** (6.4)
Inadequate care:						
Unadjusted	−30.0 (150.2)	−130.0 (104.9)	−45.0 (59.5)	−95.0 (73.1)	−70.0 (44.7)	−62.6 (49.7)
Adjusted	−37.5 (116.0)	−98.3 (74.2)	−38.3 (55.9)	−54.1 (57.9)	−100.9* (54.3)	−55.4 (51.7)
Adequate care:						
Unadjusted	−190.0 (116.5)	−200.0*** (59.2)	−25.0 (51.8)	45.0 (60.8)	100.0 (77.5)	−53.1 (46.0)
Adjusted	−164.3 (139.6)	−121.3 (78.6)	−13.0 (54.6)	46.7 (55.7)	37.2 (67.9)	−40.1 (46.8)

Notes: This table presents the mean and quantile effects of prenatal care use on birth weight, estimated using ordinary least squares (OLS) and ordinary quantile regression, respectively. The effects were estimated alternatively as unadjusted and adjusted for model covariates.
*, ** and *** indicate significance at $P < 0.1$, $P < 0.05$ and $P < 0.01$, respectively.

Mean and quantile effects of prenatal care use on birth weight

Table 3 presents the effects of the prenatal care utilization measures on BW mean and quantiles unadjusted for gestational age. Table 4 presents the same effects when adjusting for gestational age. Figures 1 and 2 show plots of these effects in the groups without and with birth defects, respectively. In both infant groups, prenatal care delay had generally insignificant effects on BW mean and quantiles, except in the group with birth defects when adjusting for gestational age, where prenatal care delay had marginally significant negative effect on BW mean (about 3.7 gm decrease per week), but had overall insignificant quantile effects when adjusting for the model covariates.

When not adjusting for gestational age, prenatal visits had significant effects on BW mean and quantiles in both infant groups. The BW mean decreased by 34 and 32 grams per visit in the groups without and with birth defects, respectively. Larger effects were observed at lower versus higher quantiles in both groups (about 59 gm decrease at the 0.1 quantile compared with 13–18 gm decrease at the 0.9 quantile). The effects were comparable overall between the two infant groups. Prenatal visits had larger effects overall when adjusting for the covariates compared with the unadjusted model.

When adjusting for gestational age, prenatal visits had significant effects on BW mean and quantiles only in the group without birth defects, reducing BW mean by 17 gm per visit. The quantile effects were also larger at lower (below median) versus higher (above median) quantiles, though the decrease in effect by quantile order was less consistent than in the model that did not adjust for gestational age. The effects of prenatal visits were generally higher when adjusting for the model covariates. No significant effects of prenatal visits were observed in the group with birth defects when adjusting for gestational age.

Inadequate care, as defined by the Kessner index, had significant effects on BW mean and quantiles only in the group without birth defects. Inadequate care reduced BW mean by 154 and 114 gm versus intermediate care when not adjusting and when adjusting for gestational age, respectively. There

Table 4 Effects of prenatal care utilization on birth weight adjusted for gestational age

Model	Quantile					Mean effect
	0.1	0.25	0.5	0.75	0.9	
Infants without birth defects						
Prenatal care delay in weeks:						
Unadjusted	2.4 (2.4)	−0.4 (1.8)	2.0 (2.0)	1.2 (2.5)	−0.2 (3.7)	1.0 (1.6)
Adjusted	3.5 (2.5)	1.5 (2.7)	3.5** (1.5)	2.2 (1.8)	2.8 (2.9)	2.1 (1.6)
Prenatal care visits:						
Unadjusted	7.5 (6.8)	14.4*** (4.5)	9.4** (4.4)	2.7 (7.5)	10.7 (8.8)	11.4*** (4.4)
Adjusted	15.0** (6.5)	24.9*** (5.4)	8.5** (3.7)	12.2* (6.2)	10.4* (5.8)	17.2*** (4.7)
Inadequate care:						
Unadjusted	−79.0 (53.5)	−89.1* (47.9)	−100.0 (73.0)	−133.6*** (49.1)	−67.0 (70.5)	−104.6*** (38.0)
Adjusted	−134.8** (51.9)	−121.4** (58.9)	−67.4 (42.5)	−114.3* (62.0)	−127.4 (80.6)	−114.1*** (38.7)
Adequate care:						
Unadjusted	−10.0 (39.6)	19.1 (30.6)	−4.0 (28.6)	−63.6 (46.6)	−18.0 (59.5)	−14.2 (29.8)
Adjusted	−23.4 (54.5)	35.1 (45.8)	−6.2 (29.4)	−73.8 (49.4)	−54.6 (69.9)	−3.7 (30.2)
Infants with birth defects						
Prenatal care delay in weeks:						
Unadjusted	−2.8 (2.9)	−5.0 (3.5)	−5.2* (2.7)	−5.0** (2.1)	−4.4* (2.6)	−3.5* (1.8)
Adjusted	−7.0 (5.2)	−2.6 (3.8)	−2.7 (3.2)	−4.4* (2.5)	−4.0 (3.8)	−3.7* (2.0)
Prenatal care visits:						
Unadjusted	−2.9 (6.1)	0.2 (6.1)	7.9 (6.4)	3.3 (8.0)	14.0** (7.0)	5.8 (5.0)
Adjusted	4.5 (6.7)	0.2 (4.5)	4.1 (6.0)	12.7 (8.0)	11.3 (12.8)	8.9 (5.5)
Inadequate care:						
Unadjusted	−35.8 (67.4)	−29.4 (65.6)	−73.3 (63.3)	−85.0 (68.0)	−100.0* (55.2)	−57.9 (44.5)
Adjusted	−47.4 (83.8)	−26.9 (62.2)	−16.5 (53.2)	64.1 (43.2)	−76.9 (60.8)	−63.3 (47.4)
Adequate care:						
Unadjusted	5.0 (52.4)	−49.4 (64.4)	−20.0 (36.7)	42.5 (40.6)	30.0 (68.3)	−23.6 (37.8)
Adjusted	−23.7 (51.9)	−77.9* (45.6)	−36.2 (46.5)	58.1 (38.5)	11.3 (50.5)	−23.8 (38.7)

Notes: This table presents the mean and quantile effects of prenatal care use on birth weight adjusting for gestational age, estimated using ordinary least squares (OLS) and ordinary quantile regression, respectively. The effects were estimated alternatively as unadjusted and adjusted for model covariates.
*, ** and *** indicate significance at $P < 0.1$, $P < 0.05$ and $P < 0.01$, respectively.

was overall no consistent pattern of larger quantile effects (in absolute value) at lower quantiles, except when the model was unadjusted for gestational age and the other covariates. The effect of inadequate care on BW mean was larger (in absolute value) when adjusting for the model covariates. Inadequate care had no significant effects compared with intermediate care in the group with birth defects.

Adequate care had insignificant effects overall compared with intermediate care in both infant groups under the various specifications. In both groups, the effects on BW mean and quantiles had the unexpected negative sign. The changes in the effects when adjusting for the other model covariates were also inconsistent.

Effects of other factors on birth outcomes

The marginal probability effects (ME) of selected prenatal factors and other covariates that showed significant effects on LBW are included in Table 5.[11] In the group without birth defects, previous live births decreased LBW risk (probability) by about 0.03 per live birth, while miscarriages/stillbirths, chronic illnesses and maternal age of 25–34 years and 35 or older (compared with 24 years or younger) increased LBW risk in this group, by about 0.02, 0.04, 0.03 and 0.08, respectively. Maternal primary and secondary education decreased LBW risk in this group by about 0.04 and 0.03, respectively, compared with incomplete primary or no education.

In the group with birth defects, previous live births, tetanus immunization, family history of birth defects, male gender and European Latin ancestry decreased LBW risk per live birth by about 0.016, 0.09, 0.013, 0.05 and 0.06, respectively. Chronic illness, older maternal age (35 years or older versus 24 years or younger), first trimester bleeding and difficulty in conception increased LBW risk by about 0.05, 0.13, 0.085 and 0.06, respectively.

Table 6 reports the ME of selected prenatal factors and other covariates that showed significant effects on preterm birth. In the group without birth defects, multivitamin use and father's secondary education (relative to incomplete primary or no education) reduced preterm birth risk by about 0.04 each,

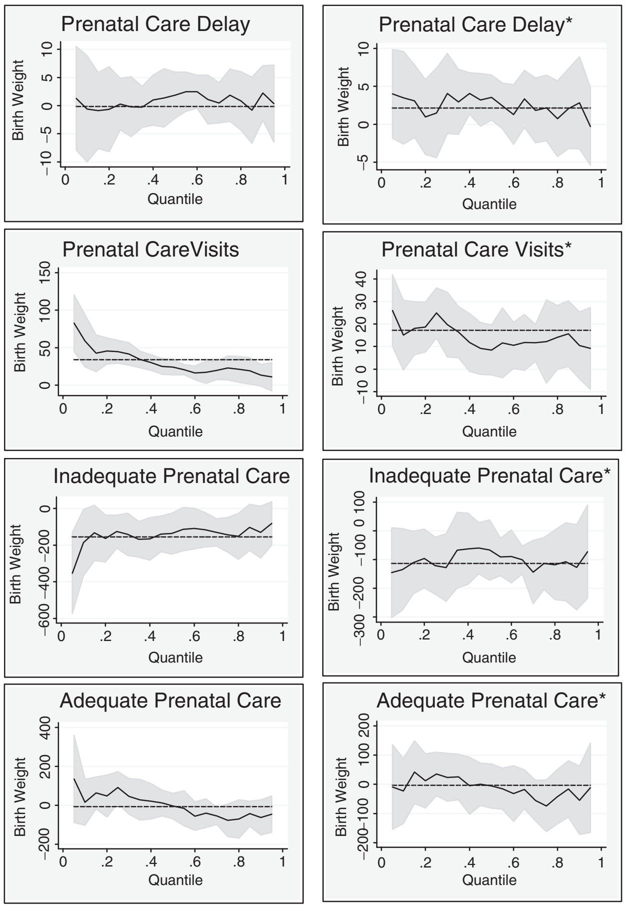

Figure 1 Quantile and mean effects of prenatal care use on birth weight in the group without birth defects
Note: Figure 1 represents the effects of prenatal care use on birth weight mean and quantiles in the group without birth defects. The dashed line represents the OLS effect on birth weight mean. Shaded areas represent the 95% confidence intervals of the quantile effects.
*indicates that gestational age was included as a covariate.

while chronic illnesses, European Latin ancestry, physical shocks, miscarriages/stillbirths and pregnancy occurrence in 2000 (relative to 1994) increased preterm birth risk by about 0.05, 0.04, 0.08, 0.02 and 0.105, respectively. In the group with birth defects, preterm birth risk decreased with maternal secondary education (versus incomplete primary or no education), birth defect history and physical shocks by about 0.01, 0.06, and 0.11, respectively. However, it increased with father's primary and secondary education (versus incomplete primary or no education), chronic illnesses and Native ancestry by about 0.06, 0.09, 0.05 and 0.05, respectively.

Figure 3 shows plots of the quantile and OLS regression effects on BW of selected prenatal factors and other covariates that had interesting results.[12] Some differences were observed in these effects between the two groups. In the group without birth defects, the number of previous live births had significant positive effects at the mean and quantiles of BW. The quantile effects at lower quantiles were generally larger than those at higher quantiles. On the contrary, previous live births had no significant effects in the group with birth defects. First trimester bleeding had large negative effects on BW mean and most quantiles in the group with birth defects, but had insignificant effects in the group without birth defects. The number of previous miscarriages and stillbirths had larger effects at lower versus higher BW quantiles in both infant groups (about 100 gm and 180 gm decrease per previous miscarriage/stillbirth at the 0.1 quantile in the groups without and with birth defects, respectively). Older maternal age (equal to or greater than 35 years compared with 24 years or younger) had large negative effects at BW mean (about 150 gm decrease)

Table 5 Marginal probability effects of prenatal factors and covariates on low birth weight

Prenatal factor/covariate	Group without birth defects ME (SE)	Group with birth defects ME (SE)
Live births	−0.029*** (0.006)	−0.016** (0.008)
Maternal primary education[a]	−0.038** (0.017)	0.001 (0.033)
Maternal secondary education[a]	−0.031* (0.017)	−0.048 (0.029)
Miscarriages/stillbirths	0.021** (0.009)	0.013 (0.015)
Chronic illnesses	0.038* (0.021)	0.048* (0.028)
Maternal age (25–34 years)	0.031* (0.016)	0.024 (0.026)
Maternal age (≥35 years)	0.082** (0.033)	0.13*** (0.038)
First trimester bleeding	0.011 (0.028)	0.085** (0.04)
Difficulty in conception	−0.012 (0.021)	0.063* (0.036)
Tetanus	−0.019 (0.025)	−0.09** (0.039)
Birth defect history	−0.009 (0.028)	−0.127*** (0.022)
Male	0.008 (0.014)	−0.05** (0.021)
European Latin ancestry	0.02 (0.016)	−0.063** (0.026)

Notes: Marginal effects (ME) of prenatal factors and other covariates on LBW probability were estimated holding model covariates at their means. Standard errors (SE) of marginal effects are listed in parentheses.
*, ** and *** indicate significant effects at $P < 0.1$, $P < 0.05$ and $P < 0.01$, respectively.

Table 6 Marginal probability effects of prenatal factors and covariates on preterm birth

Prenatal factor/covariate	Group without birth defects ME (SE)	Group with birth defects ME (SE)
Multivitamin	−0.043* (0.023)	0.001 (0.032)
Paternal primary education	0.002 (0.024)	0.062* (0.032)
Paternal secondary education	−0.043** (0.021)	0.087*** (0.032)
Chronic illnesses	0.048* (0.025)	0.046* (0.028)
European Latin ancestry	0.044** (0.019)	0.017 (0.025)
Physical shocks	0.083* (0.046)	−0.061* (0.036)
Pregnancy year 2000	0.105* (0.058)	0.015 (0.058)
Birth defect history	0.014 (0.037)	−0.108*** (0.022)
Miscarriages/stillbirths	0.022** (0.011)	0.0002 (0.015)
Maternal secondary education	−0.022 (0.023)	−0.097*** (0.027)
Native ancestry	0.014 (0.021)	0.049** (0.025)

Notes: Marginal effects (ME) of prenatal factors and other covariates on preterm birth probability were estimated holding model covariates at their means. Standard errors (SE) of marginal effects are listed in parentheses.
*, ** and *** indicate significant effects at $P < 0.1$, $P < 0.05$ and $P < 0.01$, respectively.

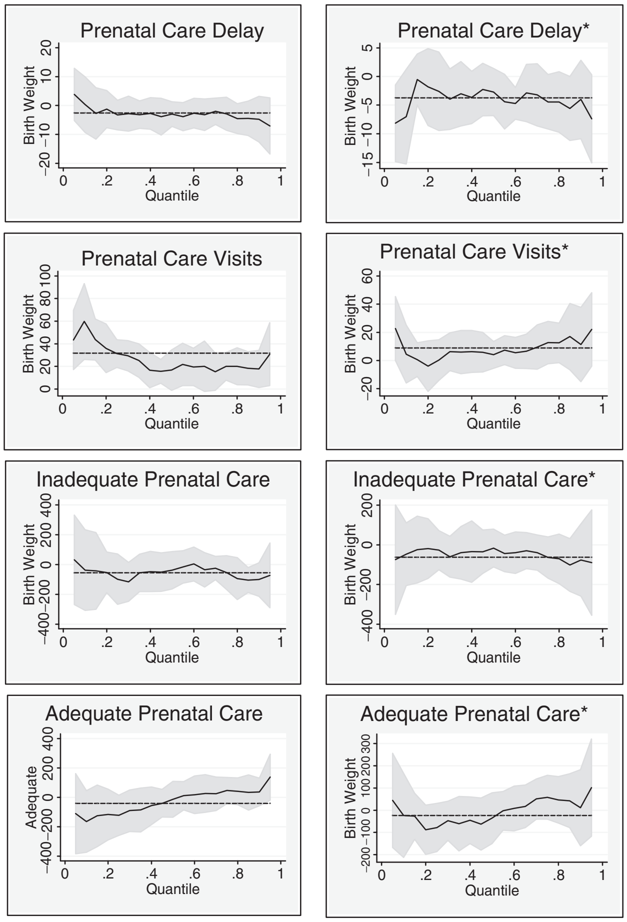

Figure 2 Quantile and mean effects of prenatal care use on birth weight in the group with birth defects

Note: Figure 2 represents the effects of prenatal care use on birth weight mean and quantiles in the group with birth defects. The dashed line represents the OLS effect on birth weight mean. Shaded areas represent the 95% confidence intervals of the quantile effects.
*indicates that gestational age was included as a covariate.

and at all quantiles in the group with birth defects, but had insignificant mean effect and negative effects only at low quantiles in the group without birth defects (generally insignificant). Maternal chronic illness had negative effects at all BW quantiles in the group without birth defects and at most quantiles in the group with birth defects, with larger effects overall at lower (<0.25) compared with higher (>0.75) quantiles, but the effects were statistically in significant overall in the group with birth defects. Finally, African ancestry had positive effects at BW mean in both groups (increase of about 61 gm; marginally significant only in the group without birth defects) and at all and most quantiles in the groups without and with birth defects, respectively.

Demand for prenatal care

The average number of prenatal visits in the study sample was about seven visits. The coefficients of the demand function for prenatal visits were not significantly different between the two infant groups using a Chow test. Table 7 reports the marginal effects of the model covariates on prenatal visits (estimated at variable means from the negative binomial regression) for the pooled sample. Difficulty in conception, acute illnesses, chronic illnesses, miscarriages/stillbirths and older maternal age increased the number of prenatal care visits, while previous live births decreased the number of prenatal care visits. Father's higher education and European non-Latin ancestry increased the number of prenatal care visits. Significant area differences in utilization were observed; a lower demand for prenatal care visits was observed in the other states compared with the state of Sao Paulo.

Table 7 Marginal effects of demand function covariates on number of prenatal care visits

Covariates	**ME (SE)**
Birth defect history	0.1 (0.1)
Difficulty in conception	0.4*** (0.2)
Acute maternal illness	0.6*** (0.1)
Chronic maternal illness	0.7*** (0.1)
First trimester bleeding	−0.002 (0.2)
Live births	−0.5*** (0.04)
Miscarriages/stillbirths	0.2** (0.1)
Maternal age (25–34 years)	0.6*** (0.1)
Maternal age (≥35 years)	1.0*** (0.2)
Maternal education–primary	0.1 (0.2)
Maternal education–secondary	0.1 (0.1)
Maternal education–university	0.03 (0.2)
Father's education–primary	−0.004 (0.1)
Father's education–secondary	0.4*** (0.1)
Father's education–university	0.7*** (0.2)
Maternal employment	0.1 (0.1)
Father's employment	0.3 (0.2)
Native ancestry	−0.2 (0.1)
African ancestry	−0.1 (0.1)
European Latin ancestry	0.04 (0.1)
European non-Latin ancestry	0.3** (0.1)
Other ancestry	−0.2 (0.3)
Pregnancy year 1995	−0.5 (0.3)
Pregnancy year 1996	−0.2 (0.3)
Pregnancy year 1997	−0.1 (0.3)
Pregnancy year 1998	−0.3 (0.3)
Pregnancy year 1999	−0.03 (0.3)
Pregnancy year 2000	0.2 (0.3)
Pregnancy year 2001	0.3 (0.3)
Pregnancy year 2002	−0.01 (0.3)
Minas Gerais	−0.7*** (0.2)
Paraiba	−2.4*** (0.3)
Rio Grande do Sul	−0.6*** (0.1)
Santa Catarina	−1.2*** (0.1)
Overall Chi-square statistic (34 df)	468.8***

Notes: The marginal effects were estimated using negative binomial regression and holding model covariates at their means. Robust standard errors of marginal effects are listed in parentheses.
** and *** indicate significant effects at $P < 0.05$ and $P < 0.01$, respectively.

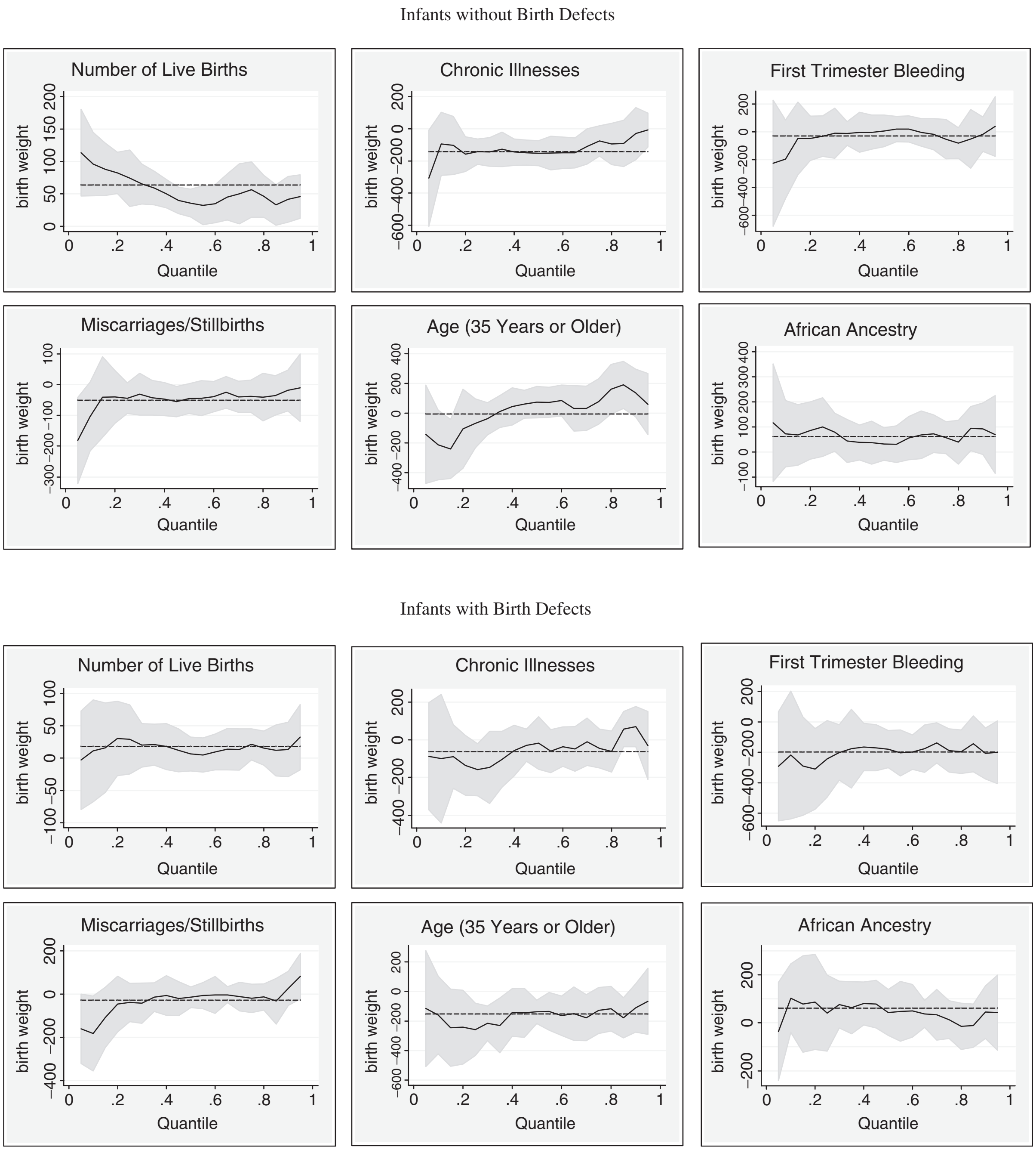

Figure 3 Quantile and mean effects of selected covariates on birth weight
Note: Figure 3 represents the effects of selected prenatal factors and other covariates on birth weight mean and quantiles. The dashed line represents the OLS effect on birth weight mean. Shaded areas represent the 95% confidence intervals of the quantile effects.

Discussion

The study analyzes the effects of prenatal care utilization on birth outcomes using an infant sample from Brazil and alternative prenatal care and birth outcome measures. The analytical approach accounts for self-selection into prenatal care through adjusting for several theoretically relevant covariates and evaluates the heterogeneity in prenatal care effectiveness by applying quantile regression and estimating effectiveness by birth defect status. Large positive effects of prenatal care visits on BW were observed for infants both with and without birth defects. However, when adjusting for gestational age, prenatal care visits had significant effects only in the group without birth defects. This suggests that prenatal care increases BW through both increasing gestational age as well as through improving fetal growth rate in pregnancies that are uncomplicated with birth defects, but that it does not improve fetal growth rate in pregnancies that are complicated with birth defects. When gestational age was not adjusted for, the estimated effects of prenatal care visits on BW were likely biased by the reverse effects of gestational age on the number of prenatal visits (longer pregnancies are more likely to have more visits). This suggests that prenatal visits are likely more effective for pregnancies that are uncomplicated with birth defects. This is supported by the significant effects of prenatal care delay on preterm birth and of inadequate care on BW in the group without birth defects and the lack of such effects in the group with birth defects.

The lack of significant effects of prenatal care delay on BW in both infant groups can be due to different factors, including measurement/recall error, self-selection into prenatal care initiation, or the relative ineffectiveness of timing of prenatal care initiation compared with the intensity of prenatal care use (i.e. number of prenatal visits). Adverse self-selection regarding timing of prenatal care initiation, which had been supported in previous studies, suggests that women at higher risk for adverse birth outcomes will initiate prenatal care earlier than those at lower risk. Adverse self-selection can also affect the other prenatal care use measures. This will result in underestimation of the effects of prenatal care use when unaccounted for. The effects of certain risk factors, such as number of live births, number of miscarriages/stillbirths and chronic illnesses, on prenatal care use and on the birth outcomes, and the change in the estimated effects of prenatal visits and the Kessner indicators when adjusted for the model covariates, provide support for the adverse self-selection hypothesis. For instance, previous number of live births reduced the number of prenatal visits but also reduced LBW risk.

Adverse self-selection can also explain the increased risks of LBW with adequate care compared with intermediate care in the group with birth defects, and the lack of significant effects of adequate care on BW in the group without birth defects. This is because high risk pregnancies are likely to get more adequate care (as defined by the Kessner index), inducing a positive bias into the estimate of effects of adequate care on LBW and a negative bias into the effects on BW. Adding indicators for the type of birth defect and whether the birth defect was diagnosed prenatally slightly reduced this bias for the group with birth defects, but the persistence of the positive effect of adequate care on LBW in this group is likely due to the role of unmeasured risks (such as certain maternal health risks) in adverse self-selection in this group.

We attempted to account for self-selection using a well-specified regression model that accounts for several theoretically relevant covariates and confounders. Due to the role of unobservable (unmeasured) risks in self-selection, it is likely that the bias in estimating prenatal care effectiveness persisted using the classical regression model. Instrumental variables (IV) analysis can be used to explicitly account for unmeasured confounders, but this requires the availability of appropriate instruments. We had no access to theoretically appealing instruments such as distance to prenatal care providers or other measures of accessibility to prenatal care.[13] Further studies are needed with datasets that provide data on instruments such as availability and price of prenatal care in order to estimate prenatal care effects using an IV model. Due to the possibility of incomplete adjustment for adverse self-selection, we consider the estimated effects of the various prenatal care measures to be lower bound estimates (i.e. prenatal care use will likely be found more effective when adjusting further for self-selection).

The quantile regression analyses suggest that pregnancies with higher fetal health risks that are correlated with lower BW quantiles will benefit more from increasing the number of prenatal visits than those with lower fetal health risks. In the group without birth defects, the larger increase in BW in the higher risk group is likely due to larger increases in both fetal growth rate and gestational age, compared with the lower risk group. In the group with birth defects, it is unlikely that prenatal care visits had a larger effect on fetal growth rate among the higher risk group compared with the low risk group.

Switching from inadequate to intermediate care (as defined by the Kessner index) was found to be more beneficial for pregnancies that are uncomplicated compared with those that are complicated with birth defects, and to result in an increase of about 110 gm in BW mean in the earlier group. The quantile regression analysis suggests that for the group without birth defects, switching from inadequate to intermediate care was slightly more beneficial in increasing BW for pregnancies with higher fetal health risks, likely through a larger effect on length of gestation compared with pregnancies with lower fetal health risks (given that this larger benefit was not observed when adjusting for gestational length). The study results also suggest that for pregnancies that are uncomplicated with birth defects, switching from inadequate to intermediate care is more beneficial than switching from adequate to intermediate care. This result is consistent with Joyce (1994) who found an increase of about 140 to 180 gm in BW mean in African American and Hispanic samples, respectively, from the US with switching from inadequate to intermediate care, but found smaller and generally insignificant effects of switching from intermediate to adequate care.

The heterogeneity in prenatal care effectiveness by quantile order suggests that prenatal care has heterogeneous effects by unmeasured fetal health risks, which include socio-economic, biologic and environmental risks that contribute to being born at lower BW quantiles. This highlights the importance of identifying women at higher risk for delivering babies at low BW quantiles, as they will benefit most from increased prenatal care utilization. Identifying this group is not straightforward but the study results suggest that first-time mothers, women with chronic illnesses or with history of miscarriages and stillbirths, and older women are more likely to belong to this group. Further studies are needed to identify predictors of this group including socio-economic, health and area characteristics. The heterogeneity of prenatal care effectiveness was masked by analysis of prenatal care effects at BW mean (using OLS), which highlights the usefulness of quantile regression as a more flexible and informative approach to estimate the effects of treatments on continuous outcomes than mean effect models, especially when treatment effectiveness is expected to vary by unmeasured risks that are expected to affect the outcome. The quantile regression results are in line overall with Abrevaya (2001), who found a larger impact of not receiving care at lower versus high BW quantiles using US natality data.

The potential ineffectiveness of prenatal care visits in improving fetal growth rate, and the lack of effects of switching from inadequate to intermediate care on BW in the group with birth defects, might be due to developmental constraints that limit potential benefits of prenatal care. The differences in the effects of measured prenatal factors and other covariates on the birth outcomes between the groups without and with birth defects (such as the effects of numbers of live births and miscarriages/stillbirths, first trimester bleeding, difficulty in conception, tetanus immunization, multivitamin use, exposure to physical shocks, history of birth defects, ancestry, infant's gender, and parental education) support the existence of different developmental processes and risks between the two infant groups. One analytical complication and also a potential contributor to the result in the birth defect group is potential heterogeneity in prenatal care effectiveness by birth defect type and severity. The sample size was relatively small to allow analyses by birth defect type. Adding indicators for the type of birth defect and for prenatal diagnosis of the birth defect had no effect overall on the primary results. Future studies with larger samples that estimate prenatal care effectiveness for each of these birth defects are needed. Another important question for future research relates to evaluating the effects of prenatal diagnosis of the congenital anomaly on birth outcomes and its potential for modifying the effects of prenatal care utilization.

Important results for other prenatal factors and model covariates were observed. The strong beneficial effects of number of previous live births in reducing LBW suggests that the decrease in fertility rates is a potential contributor to the increase in LBW rate in Brazil (and likely in the US). The average number of children per childbearing age woman decreased from about 4.31 to 3.05 in Brazil between 1980 and 1990 (Global Health Council 2006). This implies a 33% increase in LBW rate in this period based on the study estimates (see Table 5), accounting for more than 60% of the LBW rate increase reported in the Southeastern region in Brazil during this period (Goldani *et al*. 2004a). The potential effect of multivitamin use on reducing preterm birth risk deserves further evaluation in datasets that allow more specific measures of multivitamin use. First trimester bleeding increased LBW risk significantly in the group with birth defects and should be evaluated in further studies for its potential as a clinical marker for increased risks of LBW among pregnancies complicated with birth defects, in order to improve prenatal care delivery and pregnancy management. The strong positive effects of family history of birth defects in this group are interesting and might suggest larger maternal investment in prenatal health due to perception of larger risks (due to family history of birth defects).[14] This is also an important question for future research. More research is also needed to understand the increased LBW risk (in both groups) with older maternal age and how this can be addressed through prenatal care.

Unlike the US, where significantly higher rates of LBW and preterm birth are observed among African-American infants [e.g. 13.3% LBW and 17.5% preterm birth versus 6.8% and 11.1%, respectively, among whites in 2002 (Arias *et al*. 2003)], African ancestry, which was reported in more than 40% of the sample, showed some positive effects on BW. This raises interesting questions about the role of environmental, social and behavioral factors in contributing to differences in these health outcomes between white and African-American births in the US. Further research is needed to confirm and better understand these results.

The prenatal care demand results generally support the adverse self-selection hypothesis where women at potentially higher risks (e.g. acute and chronic illnesses and lower fertility) for adverse birth outcomes had more prenatal visits. This suggests that one way to increase prenatal care utilization might involve increasing women's awareness of the potential benefits of more frequent use of prenatal care, perhaps through media campaigns, since women likely respond to perceived pregnancy risks and prenatal care benefits. Prenatal care standards might also need to be modified in order to improve utilization. At least six visits are recommended in Brazil for a term pregnancy (Goldani *et al*. 2004a). More visits are recommended in more developed countries—for instance, the American College of Obstetrics and Gynecology (ACOG) recommends 15 visits for a full-term pregnancy and about 8–9 visits are recommended in Sweden for first time pregnant women (Hildingsson *et al*. 2005). Increasing the standard of care and average number of prenatal visits to 12 in Brazil is expected to improve the average BW by about 170 gm and the BW of higher risk pregnancies by about 295 gm. These fairly large effects are not surprising given the low utilization of prenatal care. The average number of prenatal visits in the study sample was 7 visits compared with 12 visits in the US, and 60% of women in the study sample initiated prenatal care in the first trimester, compared with more than 80% of women in the United States (Martin *et al*. 2005).

The geographic differences in prenatal care utilization were well correlated with differences in income per capita between the states. The average income per capita in the states of Minas Gerais, Paraiba, Rio Grande do Sul and Santa Catarina was, respectively, 58%, 35%, 70% and 80% of that in the state of Sao Paulo (Institute of Brazil for Geography and Statistics (IBGE), http://www.ibge.gov.br/, accessed 22 April 2006), suggesting that even with the existence of universal insurance and public ambulatory care clinics, average wealth at the state level still matters for prenatal care access. While there were differences in availability of clinics between the various states, these are unlikely to have accounted for all the differences observed in utilization across the studied states.

One limitation of the study is the lack of data on other potentially relevant covariates, including smoking, alcohol use and marital status. Several previous studies of prenatal care effectiveness have shown that including or excluding smoking and/or drug use in the birth outcome function had no effect on the results for prenatal care effectiveness (e.g. Joyce 1994; Warner 1998; Reichman *et al*. 2006). The majority of the study sample is expected to consist of mothers who are either married or have a stable relationship, given that about 93% of the mothers reported living with the child's father at the time of birth and that only observations with complete data on father's characteristics were included. Another potential limitation is that the included birth sample may not be fully representative nationally, given that it was selected from a non-random sample of hospitals. The distributions of the outcomes of this sample were comparable with those reported in other studies in Brazil (e.g. Goldani *et al*. 2004a; Barros *et al*. 2005), suggesting that a large sample selection bias is unlikely.[15] The hospitals participating in ECLAMC are located in socio-economically diverse communities, as can be seen from the variation of the socio-economic variables that were included in the study (see Table 1). Further, the hospitals are located in five states and several cities, providing a large geographic representation. Therefore, the sample is considered to be representative of a large proportion of the Brazilian population. While all these factors are acknowledged as limitations, they are unlikely to have had any real impact on the study results.

Finally, we had no data on the quality or content of prenatal care and the study provides results only for increasing the quantity of prenatal care at the average 'unobserved' care quality and content levels. This is a common limitation to most observational studies of prenatal care effectiveness that focus on utilization measures due to the lack of data on quality and content of care. It is expected that the estimated average effectiveness of prenatal care utilization will increase as quality and content of care increase, but it is important to also evaluate the substitutability between quantity and quality of prenatal care in improving birth outcomes. Data are needed to evaluate the effects of quality of prenatal care in improving birth outcomes.

Conclusions

The study suggests large benefits in birth weight outcomes with more frequent use of prenatal care visits and with switching from inadequate to intermediate levels of prenatal care utilization in Brazil, particularly among pregnancies with high fetal health risks but uncomplicated with birth defects. This highlights the need for health policies to improve utilization. Important future research questions are identified including further evaluation of the effectiveness of prenatal care in the presence of common birth defects.

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Endnotes

[1] Conway and Deb (2005) and Abrevaya (2001) investigated this heterogeneity using data from the US and finite mixture and quantile regression models, respectively. Most of the fetal health risks are typically unobserved (i.e. unmeasured) in datasets that are available to study prenatal care effectiveness, but the heterogeneity in prenatal care effectiveness by these risks can be evaluated using statistical models such as quantile regression. These fetal health risks can also be thought of as implying lower genetic, biologic, socio-economic and environmental endowments.

[2] The sample of affiliated hospitals and health professionals is self-selected given that participation within ECLAMC is voluntary. This is not a random sample but it has a wide geographic and socio-economic representation (the study hospitals are located in 12 cities in five states). We are unaware of large random samples in Brazil with equivalent high quality data (especially the evaluation by birth defect status).

[3] Gestational age was calculated based on the date of the last menstrual period. Other econometric studies of prenatal care have also excluded adolescent mothers for this reason. A few cases with father's age of $\leq$16 years or >65 years were excluded to avoid data errors or influential observations.

[4] This measure was set to 43 weeks for mothers who did not use prenatal care.

[5] A very small proportion of the study sample would be classified as intensive users under the APNCU. Assessing the impact of prenatal care use as defined by these adequacy measures identifies whether adequate prenatal care, as defined by the index, has an impact on infant health. If no impact is found, it remains unclear whether it is due to ineffectiveness of prenatal care or due to measurement flaws in the index itself.

[6] Other types of immunizations were rare and therefore were not evaluated in this study.

[7] More than 80% were coded as being cases of severe trauma.

[8] Income was not measured in this data.

[9] Brazil has a national public health insurance system but many (about 30%) obtain private supplemental health insurance. However, having supplemental health insurance was not measured in this data. Unfortunately, data on differences in availability and access to health care (such as provider concentration and insurance available) at the level of the city or neighbourhood where the mother resides were also not available.

[10] The poisson regression specification was rejected due to over-dispersion.

[11] Detailed results for all model covariates are available from the authors upon request.

[12] Detailed quantile regression results for all model covariates are available from the authors upon request.

[13] Most of the ambulatory health facilities in Brazil are owned by the public system (Lobato 2000) so private insurance status is likely to be an ineffective instrument. We did not have access to this data however.

[14] The effects of family history decreased when adding indicators for the birth defect types as covariates, but remained large and significant.

[15] The LBW of 11.0% in the group without birth defects is comparable with the 10% LBW rate in 1996 reported by the World Health Organization (WHO) for Brazil (especially when taking into account the increase in LBW rate over the past two decades).

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