EFFECTS OF BEHAVIORAL AND ENVIRONMENTAL FACTORS ON INFANT HEALTH

by

GULCAN CIL

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Student: Gulcan Cil

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This dissertation has been accepted and approved in partial fulfillment of the requirements for the Doctor of Philosophy degree in the Department of Economics by:

Trudy Ann Cameron	Chair
Benjamin Hansen	Core Member
Ralph Mastromonaco	Core Member
James Elliott	Institutional Representative

and

Scott L. Pratt	Dean of the Graduate School

Original approval signatures are on file with the University of Oregon Graduate School.

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DISSERTATION ABSTRACT

Gulcan Cil

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Health at birth is considered an important indicator of health outcomes in adulthood. It is also shown to have a strong association with future educational attainment and labor market outcomes. I examine the effects of behavioral and environmental factors on infant health. The factors I focus on include alcohol consumption during pregnancy, extreme weather events associated with climate change, and pollution that may result from unconventional oil and natural gas development.

In Chapter II, I examine the effects of point-of-sale alcohol warning signage that alcohol retailers are required to post in some states on alcohol use during pregnancy and on birth outcomes. I find that point-of-sale warning signs discourage alcohol consumption among pregnant women and are associated with a decrease in the odds of newborns having very low birth weight or being very pre-term. The findings of this research inform decision makers about a potentially effective mechanism through which alcohol consumption among pregnant women can be reduced. They also suggest a causal evidence for the link between prenatal alcohol exposure and inferior health at birth.

Chapter III documents that exposure to heat waves during pregnancy is associated with increased likelihood of the mother experiencing an adverse health condition during pregnancy and the newborn having an abnormal condition at birth. The results provide an assessment of the magnitude and timing of the effects of extreme heat events associated with climate change on infant health which is potentially helpful in enhancing the effectiveness of adaptation efforts.

Finally, Chapter IV provides an empirical investigation of the link between unconventional oil and natural gas development and infant health. The results indicate that unconventional drilling activity is associated with a small, but statistically significant, decline in birth outcomes, especially for those living in rural areas. Given that it is estimated that the rapid expansion in unconventional oil and gas extraction will continue for at least a few more decades, the results of this study may contribute to the discussions related to initiation or tightening of regulations and monitoring efforts to control pollution.

This dissertation includes previously unpublished co-authored material.

CURRICULUM VITAE

NAME OF AUTHOR: Gulcan Cil

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon, Eugene, OR
University of Illinois at Chicago, Chicago, IL
Middle East Technical University, Ankara, Turkey

DEGREES AWARDED:

Doctor of Philosophy, Economics, 2015, University of Oregon
Master of Arts, Economics, 2009, University of Illinois at Chicago
Bachelor of Science, Economics, 2005, Middle East Technical University

AREAS OF SPECIAL INTEREST:

Applied econometrics, environmental economics, and health economics

GRANTS, AWARDS AND HONORS:

Graduate Teaching Fellowship, University of Oregon, 2010-Present
Beatrice Aitchison Travel Award, University of Oregon, 2015
WEAI Graduate Student Dissertation Workshop Participant, Denver, CO, 2014
The Mikesell Research Paper Award, University of Oregon, 2013
Beatrice Aitchison Travel Award, University of Oregon, 2013
The Kleinsorge Summer Research Award, University of Oregon, 2012
Graduate Teaching Fellowship, University of Illinois at Chicago, 2007-2010

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CHAPTER I

INTRODUCTION

The link between an individual's health at birth and his/her future health and wellbeing is well-established in the literature.[1] Standard birth outcomes such as birth weight and gestational age can, in fact, be considered as a measure of the human capital endowment that the individual receives at birth. Therefore, for future health, education and labor market outcomes, any factor that has an impact on birth outcomes may be as important as other human capital investments that can potentially improve upon a child's endowment over time–such as years of schooling. More importantly, our ability to identify those factors which may have an adverse effect on health at birth, and to assess the magnitude, distribution and timing of these effects can be important for the effectiveness of policies that we may design to provide remediation.

This research examines the effects of different behavioral and environmental factors on infant health with the goal of quantifying systematic effects that may point to opportunities for appropriate policies to improve outcomes. Chapter II considers alcohol consumption during pregnancy and its effects on birth outcomes. High levels of prenatal alcohol exposure are known to be the cause of a serious, life-long condition known as fetal alcohol syndrome. In addition, there are studies (discussed in detail in the next chapter) that find correlational evidence suggesting that prenatal alcohol exposure is linked to inferior birth outcomes such as low birth weight and preterm birth. Consequently, reducing prenatal alcohol exposure

[1]See the Introduction and Background sections of the next two chapters for the review of this literature.

has been one of the most important public health policy goals in the U.S. over the last few decades. One of the policies adapted in 23 states and in the District of Columbia is that all alcohol retailers are required by law to post signs that warn against the risks of drinking alcohol during pregnancy. I examine the effects of these point-of-sale alcohol warning signs (AWS) on alcohol consumption during pregnancy and on birth outcomes. This research is an investigation of the effectiveness of AWS as a policy tool in reducing alcohol consumption among pregnant women. More importantly, it aims to establish a causal link between prenatal alcohol exposure and birth outcomes by using the quasi-experimental setting that results from this plausibly exogenous policy change that affects pregnant women in a subset of U.S. states.

I use the National Vital Statistics data on (a) alcohol use during pregnancy and (b) birth outcomes. The relationship between these variables are explored in a specification that accounts for state and year fixed effects, state-specific time trends, and individual- and state-level covariates. I find a statistically significant reduction in women's odds of drinking during pregnancy in response to AWS laws. This finding is supported by the results obtained using the Behavioral Risk Factor Surveillance System data in a model that compares the change in alcohol consumption before and after AWS laws among pregnant women with that of non-pregnant women. In reduced form regressions for birth outcomes, I find that AWS laws are associated with statistically significant decreases in the odds of very low birth weight and very pre-term births. These findings indicate that AWS may be an effective (and low-cost) policy tool in reducing prenatal alcohol exposure. The concomitant reduction in actual alcohol use and in the odds of very low birth weight and very preterm births support a causal link between mother's alcohol use during pregnancy and inferior birth outcomes.

Chapters III contributes to the literature that seeks to identify the adverse impact of climate change on infant health. In particular, I investigate the effects of heat waves that have occurred in the U.S. over the last two decades on birth outcomes for babies born to mothers who have been exposed to such events during gestation or during the period just prior to conception. I also consider the effects of such events on health risks for the expectant mothers themselves. I build a monthly panel data on birth outcomes and heat waves for all U.S. counties over the time period 1989 to 2008. Relative to earlier work, this updates the time dimension of the county/year panel by twenty years relative to earlier work, focusing on a more recent time period with more-detailed and more-reliable data on births and more-widespread heat waves.

To determine if there is any systematic selection into fertility associated with heat waves, I first examine potential fertility responses to heat waves. Heat waves and the birth rate in a county appear to be unrelated, and heat waves seem to produce no discernible change in the racial or educational composition of the set of mothers. Given this independence, I then separately investigate the impact of heat waves on widely used metrics such as birth weight and gestational age, and newer metrics such as the risk of experiencing a pregnancy-related health condition for the expectant mother and abnormal conditions in the newborn. I find that heat waves during the second trimester of pregnancy are associated with a slight but statistically significant decrease in average gestational age in a county, whereas there is no statistically significant impact on the fraction of births with low birth weight. I also find that exposure to heat waves during pregnancy is associated with an increase in the fraction of babies with abnormal conditions related to maternal stress, and an increase in the fraction of mothers who experience a pregnancy-related health condition.

In Chapter IV, I investigate the potential adverse impact that unconventional oil and natural gas development (UONGD) may have on infant health. Technological advancements in drilling practices have lead to a rapid expansion in UONGD in recent years, and this expansion is expected to continue for several decades. Although UONGD has several potential economic benefits at both the local and the national level, concerns have been raised about its impact on human health because of the water and air pollution that unconventional drilling process is thought to cause.

I use annual panel data on birth outcomes for counties in five states that are among the top in terms of recent UONGD expansion (including Arkansas, Colorado, North Dakota, Pennsylvania, and Texas), merged with data on the number of unconventional wells drilled in each county-year over the period of 2000-2010. I first examine how fertility and the racial and educational composition of mothers in a given county change with the number of unconventional wells drilled in the past year in that county. I find that there is a very small decrease in birth rate mainly driven by an increase in the female population (but no corresponding increase in number of births) in urban areas. The findings also indicate that there are changes in the educational composition of mothers, but no statistically discernible changes in racial composition associated with unconventional drilling activity. In particular, there are more college-educated mothers giving birth in rural counties, which may be a result of increased fertility among more educated women in these counties in response to a disproportionate change in economic conditions for this group. Having more births to college-educated mothers in counties with more unconventional drilling activity would suggest that we may observe improvements in birth outcomes in these communities, rather than adverse health effects. However, the results of the model for birth outcomes suggest that there is a small but statistically significant decrease in the average birth weight in a given county-year associated with the number of unconventional wells drilled in that county in the past year. The effect seems to be bigger for rural areas. These findings suggest that UONGD may have an adverse impact on birth outcomes and the main mechanism through which it operates may be water contamination.

Chapter V summarizes the findings and discusses the policy implications that the findings in each chapter may have briefly.

Chapter III and Chapter IV include previously unpublished material co-authored with Trudy Ann Cameron and Ralph Mastromonaco, respectively.

CHAPTER II

EFFECTS OF POSTED POINT-OF-SALE WARNINGS ON ALCOHOL CONSUMPTION DURING PREGNANCY AND ON BIRTH OUTCOMES

Introduction

According to the Centers for Disease Control and Prevention (CDC), prenatal exposure to alcohol is a leading preventable cause of birth defects and developmental disorders in the U.S. (CDC, 2004). The most severe result of prenatal alcohol exposure is fetal alcohol syndrome (FAS) which is a lifelong condition characterized by a specific pattern of abnormal facial features, growth retardation, and central nervous system abnormalities (Barry et al., 2009). It is estimated that 0.5 to 2.0 cases per 1,000 live births are affected by FAS and such rates are comparable with (or above) other common developmental disabilities such as Down syndrome or spina bifida (CDC, 2004). Even moderate levels of alcohol exposure in utero are thought to be linked to other mental, behavioral, and/or learning disabilities in the child, including inattention, hyperactivity, memory deficits and psychiatric problems. (See Sokol et al., 2003 for this literature.) Moreover, studies in the epidemiology literature suggest a correlation between prenatal alcohol exposure and inferior birth outcomes assessed by standard measures of health at birth such as birth weight and gestational age (e.g. Kesmodel et al., 2000; Whitehead and Lipscomb, 2003; Truong et al., 2012).

Despite the potential harmful effects of prenatal alcohol consumption, the prevalence of drinking during pregnancy remains at troubling levels. One of the goals established in “Healthy People 2010” by the US Department of Health and Human Services was to increase the number of pregnant women who report abstinence from alcohol use from a baseline rate of 90% in year 2002 to a 2010 target of 95% . But the final review of the target in 2012 indicates no change in the prevalence of drinking during pregnancy (NCHS, 2012). Therefore, prevention of prenatal alcohol exposure is still one of the most important public health policy goals, as it has been over the past three decades.

One of the policies that has been implemented to reduce alcohol consumption while pregnant involves point-of-sale warning signs. From the mid-1980s through the 2010s, 23 states and the District of Columbia implemented laws which require all alcohol retailers to post signs that warn against the risks of drinking during pregnancy. This study examines the effect of these point-of-sale alcohol warning sign (AWS) laws on alcohol consumption during pregnancy and on birth outcomes using a generalized difference-in-differences approach.

The contributions of this study are two-fold. First, this research is an investigation of the effectiveness of AWS as a policy tool to reduce alcohol use among pregnant women. The posting of warning signs is a low-cost policy that can be relatively easy to implement. Any positive effect that this policy may have on drinking behavior and on birth outcomes may be considered a valuable gain. To my knowledge, this study is the first attempt to evaluate the effectiveness of point-of-sale AWS as a policy tool in reducing prenatal alcohol use.

Second, fetal development is considered one of the most important factors in a child's later development (Currie, 2011). It is well-established in the literature that there is a strong association between poor health at birth and subsequent worse socioeconomic and health-related outcomes later in life and that birth outcomes are an important indicator of individual's future wellbeing (See Currie, 2009;

Almond and Currie, 2011a; and Almond and Currie, 2011b). Although there is correlational evidence concerning the association between prenatal alcohol exposure and standard measures of birth outcomes, conclusive evidence for a causal link between the two is lacking. This is largely because drinking while pregnant is likely to be associated with other factors that have a direct impact on birth outcomes (such as smoking, drug abuse, other risky behaviors and lifestyle choices), which makes it hard to isolate the causal relationship between prenatal alcohol use and birth outcomes. Based on a quasi-experimental setting that results from a plausibly exogenous policy change, this study takes an important step towards establishing a causal link between alcohol use during pregnancy and standard measures of health at birth.

This study is not the first attempt to take advantage of policy changes to overcome the potential endogeneity between drinking during pregnancy and other unobservable factors affecting birth outcomes. One other such policy change has been the minimum legal drinking-age (MLDA) laws. Fertig and Watson (2009) use variation in the timing of changes in the MLDA across the states to examine the effects of access to alcohol on birth outcomes. They find that a lower MLDA is associated with a higher incidence of low birth weight and premature birth among births to young mothers. In a more recent study, however, Barreca and Page (2012) find little or no relationship between MLDA and the health of infants born to young mothers. The authors of these studies point out that more-lenient MLDA laws are likely to change the composition of births by increasing unintended teen pregnancies and/or by increasing the proportion of healthy infants through its effect on fetal loss and the associated positive selection of surviving fetuses. This may imply that any change in birth outcomes that has been observed in the data may be a reflection merely of these compositional changes. Therefore, the independent effects on birth outcomes of maternal alcohol consumption remain largely unknown.

One advantage of using AWS laws to identify the effects of prenatal alcohol exposure on birth outcomes is that AWS laws are unlikely to have any effect on fertility decisions. Moreover, AWS laws target all women of childbearing age, whereas minimum legal drinking-age laws affect only a subset of women of childbearing age.

Using the National Vital Statistics (NVS) data and an empirical specification that accounts for individual- and state-level covariates, state and year fixed effects, and state-specific time trends, I find that AWS laws are associated with a decrease in alcohol consumption during pregnancy. This finding is supported by other results obtained using the Behavioral Risk Factor Surveillance System (BRFSS) data in a regression model that compares the change in alcohol consumption before and after the passage of AWS laws for pregnant women with the same change for non-pregnant women.

Having found evidence of a reduction in alcohol use during pregnancy in response to AWS laws, I use this plausibly exogenous change in drinking behavior to identify the effects of prenatal alcohol exposure on birth outcomes. I estimate the effects of AWS laws on birth outcomes in reduced form regressions, and find that AWS laws are associated with decreases in the odds of the child having very low birth weight and being born very pre-term. I perform a sensitivity analysis in which I use the indicators for being born below different birth weight and gestational age thresholds as the outcome variables. The results of this sensitivity analysis indicate that the estimated impact of AWS on the odds of very low birth weight and very pre-term birth is not merely a result of the researcher's choice of the thresholds for birth weight and gestational age. In fact, the effect on the odds of being born with a birth weight that is below a certain threshold is the largest for the lowest range of birth weight thresholds.

Finally, I observe that AWS laws have no statistically discernible effect on whether the newborn is diagnosed with FAS. This may stem from the fact that only a tiny fraction of newborns are diagnosed with FAS in the data because FAS is rarely diagnosed as early as birth. I also find that AWS laws are not associated with Apgar scores, or whether the mother smoked while pregnant.

The rest of the paper proceeds as follows. Section 2 provides a brief background on AWS laws. Section 3 describes the data. In Section 4, the empirical models and estimation results are presented and discussed. In Section 5, the results of falsifications tests and robustness checks are presented. Section 6 concludes.

Background

A U.S. Surgeon General's advisory released in 1981 concluded that there is no known safe amount of alcohol to drink during pregnancy and suggested that pregnant women limit the amount of alcohol they drink.[1] Since then, one of the steps that the states have taken towards reduction of prenatal alcohol consumption is to require alcohol retailers to post signs that warn against the risks of drinking during pregnancy. These point-of-sale warning signs can be considered as an educational campaign that promotes abstinence from prenatal alcohol use by raising awareness and informing expecting mothers of the potential consequences of drinking during pregnancy. These signs may also have an affect on drinking

[1] In 2005, the Surgeon General updated the recommendation to complete abstinence from alcohol during pregnancy.

behavior during pregnancy by changing social norms about alcohol use during pregnancy. They may make drinking while pregnant a less tolerated behavior, which may, in return, discourage pregnant women from drinking regardless of their personal beliefs about the risks created by drinking while pregnant. Regardless of the mechanism through which they operate, AWS may result in a reduction in alcohol consumption among pregnant women.

Despite the fact that AWS are potentially a cost-effective policy in reducing alcohol use during pregnancy, only 23 states (and the District of Columbia) have adopted this policy. Table 1 lists the states that have AWS laws, and includes the month and year of adoption for each state. Although adopted at different times in different states, AWS laws show similarities across states. For instance, they typically apply to both on-premises and off-premises alcohol license holders (i.e. liquor stores and grocery stores, as well as bars and restaurants serving alcohol).[2] Moreover, the messages displayed in the signs and other requirements related to the placement and appearance of the signs are fairly similar. Therefore, it is reasonable to assume that the information treatment is approximately the same in all states that have AWS laws.

It is worth pointing out that there are cities and counties that have adopted this policy in the absence of state-wide legislation. For instance, New York City issued the first municipal ordinance that required AWS in certain establishments in 1983, eight years before AWS legislation was passed state-wide. These cities and counties are treated as the part of the control group in the empirical analysis in this study, which may result in underestimation of the effects of AWS laws.

[2]With the exceptions of Georgia, Nevada and Texas (on-premises only), and North Carolina (off-premises only).

TABLE 1. Alcohol warning signs laws

State	Date Passed*	State	Date Passed*
Alaska	June 1989	New Jersey	February 1993
Arizona	May 1991	New Mexico	April 1991
California	November 1986	New York	April 1991
Delaware	May 1989	North Carolina	July 2003
Georgia	April 1986	Oregon	June 1991
Illinois	September 1989	South Dakota	February 1986
Kentucky	April 1992	Tennessee	May 1997
Minnesota	April 1996	Texas	May 2007
Missouri	June 2001	Utah	March 2011
Nebraska	February 1989	Washington**	May 1993
Nevada	May 2003	West Virginia	March 1998
New Hampshire	June 1991		

* Month and year that the bill is approved by the governor.

** Washington repealed the alcohol warning sign requirement in November 2011.

The only federal regulation that addresses drinking during pregnancy is the Alcoholic Beverage Warning Label Act of 1988. This law requires that a label warning women not to drink alcoholic beverages during pregnancy because of the risk of birth defects must be attached to all containers of alcoholic beverages. [3] The findings in the studies that examine the impact of container warning labels on alcoholic alcohol consumption indicate mixed results (e.g. Hankin et al., 1993; Greenfield and Kaskutas, 1998; Hankin et al., 1998; MacKinnon et al., 2001; Argo and Main, 2004). One factor that may limit the effectiveness of the warning labels on beverage containers is that only the consumers who come into contact with the beverage containers are exposed to the warning message. consumers are less

[3]The law requires the message should be worded exactly as follows: "Government Warning: (1) According to the Surgeon General, women should not drink alcoholic beverages during pregnancy because of the risk of birth defects. (2) Consumption of alcoholic beverages impairs your ability to drive a car or operate machinery, and may cause health problems."

likely to come into contact with the beverage containers, and thus less likely to be exposed to the warning message, while consuming alcohol in a restaurant or a bar.

There are also studies, especially in the marketing literature, that consider the effectiveness of warning posters for other alcohol hazards and other drinking-related educational public health campaigns on the perception of risks associated with drinking and on alcohol use (e.g. Kalsher et al., 1993; Agostinelli and Grube, 2002; Deshpande et al., 2005). However, literature that specifically focuses on AWS is limited.

In a study by Fenaughty and MacKinnon (1993), the authors assess the effects of AWS legislation in Arizona on college students' exposure to and awareness of the signs, beliefs about the risks of drinking alcohol while pregnant, and memory of the warning. They find that introduction of the warning signs is associated with greater exposure, awareness, and memory, but they find inconsistent evidence for an association between the introduction of the warning signs and beliefs about the relationship between maternal alcohol consumption and birth defects. In a later study, MacKinnon et al. (1999) find some suggestive evidence for an association between AWS legislation in Arizona and (a) stronger beliefs among college students about the risks of drinking while pregnant and (b) less tolerance for alcohol consumption during pregnancy, but they find no significant effects of AWS on intentions to avoid drinking alcohol while pregnant.

This study focuses on the effects of AWS on alcohol consumption among pregnant women and on birth outcomes. If AWS laws do have an impact on drinking behavior while pregnant, then the variation in the timing of AWS laws across the states can be used to identify the effects of alcohol use during pregnancy on birth outcomes.

Data

The main data source is the National Vital Statistics Natality Detail Files (NVS). These data are derived from information reported on birth certificates. In addition to the information on newborn's health at birth, the data contain information on the mother's age, race, education, and marital status as well as her state of residence. The birth certificate data also include questions on alcohol consumption during pregnancy starting 1989, and this information is included in the publicly available version of the data until 2006. With the exception of California and South Dakota, all states reported alcohol use across all or most of the time period 1989-2006.[4]

One concern about using birth certificate data in estimating the effects of AWS on drinking during pregnancy is that, as also reported in data documentation (Martin et al., 2003), alcohol use is substantially underreported on the birth certificates, compared with data collected in other nationally representative surveys of pregnant women. Over time, Figure 1 shows (a) reported drinking during pregnancy from birth certificates, as well as (b) reported drinking in the last thirty days among pregnant women in the Behavioral Risk Factor Surveillance System (BRFSS), which is a national survey of adults concerning their behavioral health risk factors, including alcohol consumption. The figure shows that more than 10% of pregnant women in the BRFSS report drinking alcohol in the past thirty days, whereas only about 1% of new mothers report alcohol consumption while pregnant in the birth certificate data. Although the underreporting of drinking while pregnant may lead to issues related to statistical power, it does not result in

[4]See Table Appendix Table 23 for data availability on alcohol consumption in the NVS by state and year.

bias in the estimated effects of AWS on drinking during pregnancy, provided that the extent of underreporting is not correlated with the adoption of AWS laws. If the adoption of AWS laws results in an increase in the number of women who drink during pregnancy but choose not to report it, however, then the effect of AWS on drinking behavior might be overestimated.

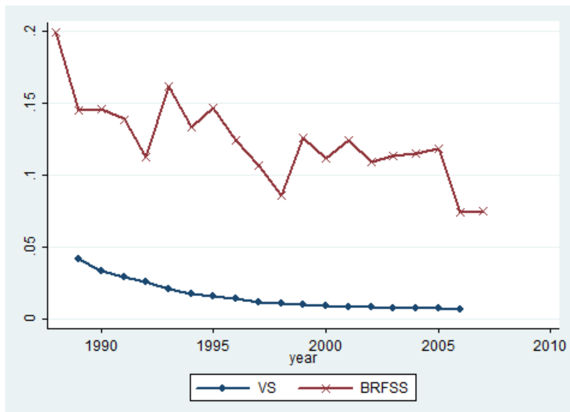

FIGURE 1. Trends in alcohol consumption during pregnancy

As a supplementary data source to investigate the effects of AWS laws on drinking during pregnancy, I use the BRFSS. The BRFSS includes information on each respondent's state of residence, race, age, education, marital status, and pregnancy status, as well as alcohol consumption in the last thirty days. The advantage of using this data source is that drinking among pregnant women is less likely to be underreported because the BRFSS is a telephone survey where a drinking pregnant respondent may feel less pressure to withhold that they have been drinking while pregnant. Another reason is that, in the BRFSS, the questions related to drinking behavior were asked before the ones related to pregnancy status, at least until 2006. Therefore, respondents reveal whether they drink alcohol before they are asked if they are pregnant.[5]

In addition to examining the effects of AWS laws on drinking during pregnancy, I consider the effects on birth outcomes. The data on standard measures of health at birth, such as birth weight and gestational age, are available on birth certificates starting in the late 1960s. These data enable me to broaden the time period used in my regressions for birth outcomes to 1980-2010 so that at least five years of data for the pre-treatment (i.e. pre-implementation) period can be included for all states that have AWS laws. Robustness checks have been performed to test whether the results from these regressions for birth outcomes also hold for during time period, and for the sample, that I use for the alcohol consumption regressions.

As discussed in the next section, my identification strategy relies on the variation in the timing of AWS legislation across states. Accordingly, the sample is restricted in all regressions to women older than 21 who live in the states that have ever adopted an AWS law.

[5]The problem with using the BRFSS data, however, is that the survey was not fielded in all states until 1996, which reduces the number of observations for early years when the majority of the adopting states passed AWS laws. Moreover, the questions related to alcohol use have been one of the optional modules in the questionnaire and have not been asked in each state in every year. Especially during the 1990s, data on alcohol consumption is available for all states in all odd-numbered years but for only a handful of states in the even years. This means that for some states that have AWS laws, data is not available on either side of the year when AWS legislation has passed. See Appendix Table 24 for data availability of alcohol related questions in the BRFSS by state and year.

Empirical Model and Results

Effects on Alcohol Consumption

Vital Statistics

I begin by estimating the effect of the presence of an having AWS law in a given state on alcohol consumption during pregnancy using the linear probability model in the following equation:

$$y_{ist} = \beta AWS_{st} + X_i \cdot \gamma + X_{st} \cdot \xi + \delta_s t + \theta_s t^2 + \alpha_t + \alpha_s + \epsilon_{ist} \qquad (2.1)$$

where i indexes individuals, s indexes states and t indexes years. The outcome variable is a binary indicator that is equal to one if new mother i, giving birth in state s in year t, reported alcohol consumption during pregnancy. The variable AWS_{st} is a binary indicator that equals one if an AWS law was in force in state s and year t. β represents the estimated relationship between AWS laws and drinking during pregnancy. X_i is a vector of individual-level controls including indicators for race (white (omitted category), black, and other non-white), age group (aged 22 to 25 (omitted category), 26 to 29, 30 to 34, and greater than 35), education level (less than high school education (omitted category), only high school education, and college education or more), and marital status. X_{st} is a vector consisting of two time-varying state-level controls–beer taxes and unemployment rate.[6] $\delta_s t$ and $\theta_s t^2$ capture any linear or quadratic state-specific time trends. The goal in adding state-specific time trends is to account for unobserved factors varying smoothly over

[6]Beer taxes indicate the tax rate per 31-gallon barrel that is effective in state s in the last nine months. The data on beer taxes are obtained from National Institute on Alcohol abuse and Alcoholism (Ponicki, 2004) and Brewers' Almanac. In all regressions, the unemployment rate is a moving average of the unemployment rate in state s in the last twelve months relative to month of birth.

time in each state that are potentially correlated with both the adoption of AWS and the outcome variables. Finally, α_t and α_s are state and year fixed effects. The standard errors are clustered at state level.

Table 2 reports OLS estimates for this linear probability model designed to capture the relationship between AWS laws and drinking during pregnancy. Estimates for a version of the model with state-specific trends which are simply linear are presented in column (1). These results suggest that AWS laws lead to a 0.26 percentage point decrease in drinking during pregnancy. When the state-specific time trends are allowed to be quadratic, the estimate of β, presented in column (2), is smaller in magnitude but remains statistically significant. The estimate of β in this specification implies that adoption of AWS laws is associated with a 0.16 percentage point decrease in drinking during pregnancy, which corresponds to an 11% (of the mean) decrease in the proportion of new mothers reporting drinking while pregnant.

TABLE 2. Alcohol warning signs laws and drinking during pregnancy - NVS

	(1)	(2)
AWS	-0.00257*	-0.00164*
	[0.00127]	[0.00081]
N	21,427,399	21,427,399
R^2	0.013	0.013
Mean	0.0148	0.0148
Std. Dev.	0.121	0.121
Year FE	Yes	Yes
State FE	Yes	Yes
Covariates	Yes	Yes
State-specific trends	Linear	Quadratic

Robust standard errors in parentheses, clustered at state level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

BRFSS

Using the sample of pregnant women in the BRFSS, I estimate the effect of AWS laws on drinking while pregnant, β, in equation (1) above. Two outcome variables are available: One is a binary indicator that equals one if the respondent reported drinking in the last thirty days, and the other is a binary indicator for any binge drinking in the last thirty days.[7] The estimates of β in the models with state-specific linear and quadratic time trends are presented in Table 3. The estimated coefficients for both outcome variables are negative but they are not statistically significant in any of these models. This may stem from the fact that only 0.9% of all respondents and 4.2% of the women of child bearing age in BRFSS are pregnant. This implies that the sample size for this specification is quite small, leaving very few observations in some of the state-year cells.

To deal with this problem, I use an alternative specification where I take advantage of having information on both pregnant and non-pregnant women in BRFSS. Instead of focusing on pregnant women and using the variation in timing of the treatment (passage of AWS legislations) across the states, I use the entire sample of women and use variation in pregnancy status to identify the effects of AWS laws on drinking during pregnancy. That is, the identification of the effect of the AWS laws relies on the differences across pregnant and non-pregnant women in alcohol consumption before and after AWS laws pass with the assumption that AWS laws have an effect on behavior only for pregnant women, and non-pregnant women do not change their alcohol consumption in response to AWS laws. If AWS

[7] The definition of binge drinking in the BRFSS is five or more drinks on one occasion until 2006. Since then, it refers to having four or more drinks on one occasion.

TABLE 3. Alcohol warning signs laws and alcohol consumption and binge drinking solely among pregnant women - BRFSS

	(1) Drinking		(2) Binge drinking	
AWS	-0.00773	-0.00342	-0.00097	-0.00104
	[0.01522]	[0.02024]	[0.00679]	[0.00941]
N	18,234	18,234	18,195	18,195
R^2	0.065	0.066	0.017	0.018
	0.119	0.119	0.0175	0.0175
	0.324	0.324	0.131	0.131
Year FE	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes
State-specific trends	Linear	Quadratic	Linear	Quadratic

Sample weights provided in BRFSS data are used.
Robust standard errors in parentheses, clustered at state level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

laws result in a decrease in drinking among non-pregnant women, then this may result in underestimation of the effects of AWS laws.

Using the sample of all women aged 21 to 44 in the BRFSS, I estimate the equation given below:

$$
\begin{aligned}
y_{ist} &= \beta(Pregnant_{ist} * AWS_{st}) + \lambda Pregnant_{ist} + \pi AWS_{st} + X_i \cdot \gamma + X_{st} \cdot \xi \\
&+ \delta_s t + \theta_s t^2 + \alpha_t + \alpha_s + \epsilon_{ist} \qquad (2.2)
\end{aligned}
$$

where $Pregnant_{ist}$ is a binary indicator that equals one if respondent i living in state s is pregnant. X_i and X_{st} denote the same set of individual- and state-level covariates listed above, and the outcome variables are again indicators for any alcohol consumption and any binge drinking in the past thirty days. In the baseline model, separate state fixed effects and year fixed effects together with state-specific time trends are included. The more flexible version of the model includes state-by-year fixed effects subsuming the AWS_{st} indicator. If AWS laws result in a decrease in alcohol consumption among pregnant women, we should observe a negative coefficient on the $Pregnant * AWS$ interaction term, β. The errors are again clustered at the state level.

The OLS estimates for β are presented in Table 4. The results indicate that AWS laws are associated with a decrease in alcohol consumption and binge drinking among pregnant women. The coefficient estimates for β, in the models with state-specific time trends and in the flexible model with state-by-year fixed effects are very similar and imply that the adoption of AWS laws is associated with a roughly 13% decrease in alcohol consumption, and a 16.7% percent decrease in binge drinking. These results imply a larger change in behavior in response to AWS laws than is apparent in the NVS data.

TABLE 4. Alcohol warning signs laws and alcohol consumption and binge drinking among all women using the variation in treatment status - BRFSS

	(1) Drinking			(2) Binge drinking		
Pregnant*AWS	-0.06745**	-0.06689**	-0.06631**	-0.01897*	-0.01900*	-0.01962*
	[0.02621]	[0.02613]	[0.02574]	[0.00973]	[0.00973]	[0.00956]
Pregnant	-0.3402***	-0.3405***	-0.3416***	-0.0874***	-0.0874***	-0.0871***
	[0.02685]	[0.02670]	[0.02653]	[0.00964]	[0.00962]	[0.00940]
AWS	0.00361	0.01611		0.00042	0.00453	
	[0.00968]	[0.01469]		[0.00502]	[0.00627]	
N	442,858	442,858	442,858	439,946	439,946	439,946
R^2	0.118	0.119	0.122	0.040	0.040	0.039
Mean	0.514	0.514	0.514	0.114	0.114	0.114
Std. Dev.	0.500	0.500	0.500	0.318	0.318	0.318
Year FE	Yes	Yes	No	Yes	Yes	No
State FE	Yes	Yes	No	Yes	Yes	No
State-by-year FE	No	No	Yes	No	No	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
State-specific trends	Linear	Quadratic	None	Linear	Quadratic	None

Sample weights provided in BRFSS data are used. Robust standard errors in parentheses, clustered at state level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Effects on Birth Weight and Gestational Age

The estimates discussed in the previous section suggest that AWS laws lead to a decrease in alcohol consumption among pregnant women. If alcohol consumption during pregnancy has a negative impact on birth outcomes, then this change in behavior might be observed as an improvement in birth outcomes. Using the specification in equation (1) above, I estimate the association between AWS laws and four different outcome variables. I examine whether newborn i in state s in year t (1) had low birth weight (birth weight less than 2500 grams), (2) had very low birth weight (birth weight less than 1500 grams), (3) was pre-term (gestational age less than 37 weeks), or (4) was very pre-term (gestational age less than 32 weeks).

The key coefficient estimates, presented in Table 5, are negative for all four outcomes, implying that AWS laws may be associated with a decrease in the odds of these adverse birth outcomes. However, these coefficients are statistically significant only for the outcomes of very low birth weight and very pre-term birth in the flexible model when the state-specific time trends are allowed to be quadratic.

The interpretation of the findings in panel (2) is that AWS laws are associated with a 0.04 percentage point decrease in the chance of very low birth weight. Considering that very low birth weight is a rare condition affecting only 1.25% of all births, this change corresponds to a 3.2% decrease in chance of very low birth weight, relative to previous levels. The findings in panel (4) indicate a 0.05 percentage points decrease in the odds of very pre-term birth in response to AWS laws, which corresponds to a 3% change from a baseline prevalence of 1.59%.

The birth weight and gestational age thresholds used in the regressions in Table 5 are based on the commonly used but arbitrary definitions for low birth weight, very low birth weight, pre-term birth and very pre-term birth. To ensure that the coefficient estimates obtained are not simply a result of these arbitrary choices of cut-offs for birth weight and gestational age, I repeat the regressions for different possible birth weight and gestational age thresholds. Figure 2 plots the β-coefficient estimates with their 90% confidence intervals for equation (1) where

TABLE 5. Whether (1) had low birth weight, (2) had very low birth weight, (3) was pre-term, (4) was very pre-term.

	(1) Low Birth Weight <2500g		(2) Very Low Birth Weight <1500g		(3) Pre-term <37 weeks		(4) Very pre-term <32 weeks	
AWS	-0.00010	-0.00085	-0.00003	-0.00040*	-0.00198**	-0.00057	-0.00040	-0.00047*
	[0.00102]	[0.00078]	[0.00034]	[.00020]	[0.00094]	[.00146]	[.00033]	[.00027]
N	48,711,250	48,711,250	48,711,250	48,711,250	42,957,789	42,957,789	42,957,789	42,957,789
R^2	0.012	0.012	0.004	0.004	0.011	0.011	0.005	0.005
Mean	0.0697	0.0697	0.0125	0.0125	0.105	0.105	0.0159	0.0159
Std. Dev.	0.255	0.255	0.111	0.111	0.307	0.307	0.125	0.125
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific trends	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic

Robust standard errors in parentheses, clustered at state level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

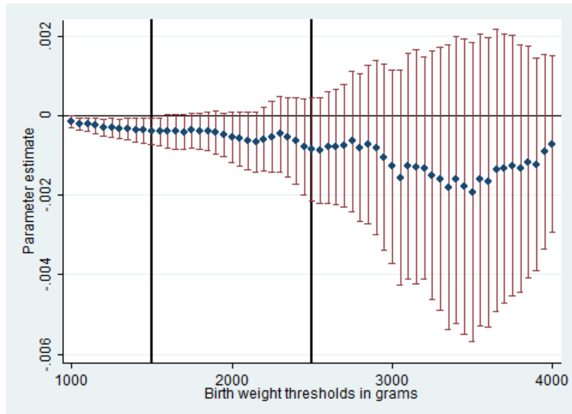

FIGURE 2. Estimates for the coefficient β in equation (2) for other birth weight thresholds besides just 1500g and 2500g (based on specifications with state FE, year FE and state-specific quadratic time trends)

the outcome variables are binary indicators for birth weights below different thresholds ranging from 1000 grams to 4000 grams. That is, each point and error-bar combination shown in the plot represents the effect of AWS laws on the chance of a birth weight less than the birth weight threshold shown in the horizontal axis. The estimates presented in the second and fourth panels of Table 5 for low birth weight and very low birth weight thresholds are included in the figure and are highlighted by vertical lines on the plot. The figure suggests that the coefficient estimates are negative and statistically significant for all possible thresholds in the lowest range of birth weights, suggesting that the results are not uniquely sensitive to any one choice of birth weight cut-off.

Although the point estimate of the impact of AWS laws seems to be smaller for the lowest birth weight thresholds, the impact in percentage terms is larger. This stems from the fact that the proportion of newborns with extremely low birth weights is very small compared to the proportion of newborns with healthy birth weights. In fact, the semi-elasticity between AWS and birth weight, calculated by dividing the coefficient estimate by the mean of the respective dependent variable, is the highest for the lowest birth weight thresholds. Figure 3 displays the semi-elasticity estimates for each of these alternative birth weight thresholds with their 90% confidence intervals. The results imply that AWS laws lead to an improvement of about 3% in the chance of extremely low birth weight regardless of the cut off chosen. The effect gets smaller, and becomes statistically insignificant, as the birth weight cut offs increase to healthier levels.

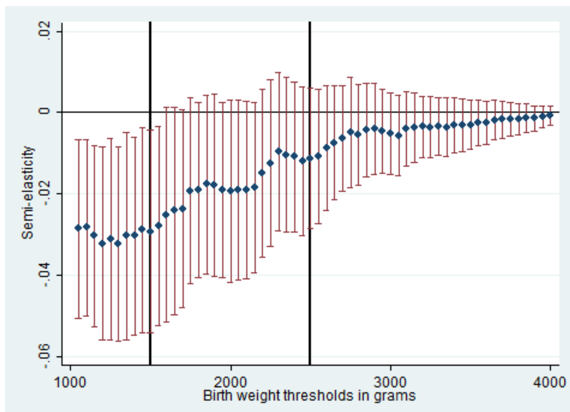

FIGURE 3. Estimates for the semi-elasticity of birth weight with respect to AWS, for other birth weight thresholds besides just 1500g and 2500g (based on specifications with state FE, year FE and state-specific quadratic time trends)

Similarly, Figure 4 plots the coefficient estimates for the effect of AWS laws on the chance of a gestational age below different thresholds from 25 weeks to 40 weeks. AWS laws do seem to matter for the chance of a gestational age less than 30, 31 or 32 weeks. But the measured effect is not statistically significant for gestational age cut offs that are lower than 30 weeks. One explanation for this may be that extreme prematurity is a rare condition that results from health complications that are not related to prenatal alcohol exposure. Only 0.8% of births in the sample involved a gestational age less than 29 weeks. These small numbers may make outliers very influential. Looking at Figure 5 where the semi-elasticity estimates for each different gestational age cut-off are presented, the statistically significant estimates of the effects of AWS laws correspond to a 2.5-3% decrease in the chance of having a gestational age that is lower than the corresponding threshold.

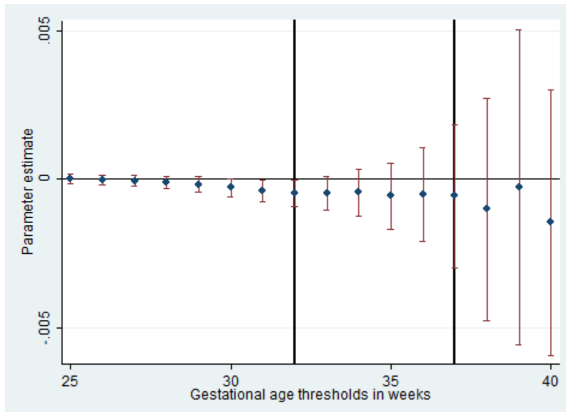

FIGURE 4. Estimates for the coefficient β in equation (2) for other gestational age thresholds besides just 32 and 37 weeks (based on specifications with state FE, year FE and state-specific quadratic time trends)

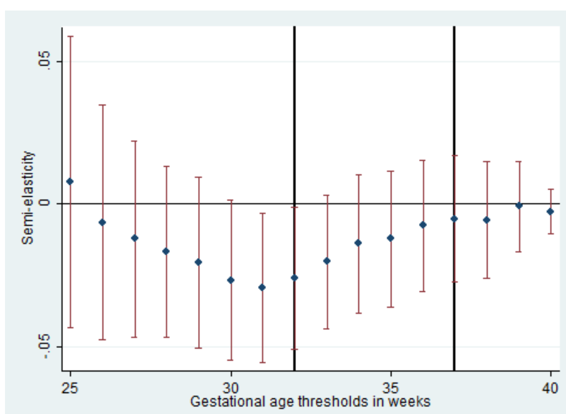

FIGURE 5. Estimates for the semi-elasticity of gestational age with respect to AWS, for other gestational age thresholds besides just 32 and 37 weeks (based on specifications with state FE, year FE and state-specific quadratic time trends)

Effects by Birth Order

There are two main mechanisms through which AWS may have an effect on drinking behavior among pregnant women. The information presented on the warning signs may educate women, and change their beliefs, about the risks of alcohol consumption during pregnancy. If this is the main mechanism through which these signs discourage drinking among pregnant women, then we might expect to see a larger impact on alcohol consumption among first-time mothers. That is, if a woman had consumed alcohol during a pregnancy and subsequently had a seemingly healthy child, she may tend to rely on this personal experience in making a judgment about the risks involved in drinking alcohol in her later pregnancy, rather than using the information presented in the warning signs. In that case, AWS may not be very effective in changing perception of the risks, and thus may result in a smaller change in prevalence of drinking among these women compared to women who are pregnant for the first time.

Another mechanism could be that AWS may change social norms about drinking alcohol while pregnant such that pregnant women may shy away from drinking alcohol regardless of their personal beliefs about the potential harm that it may cause. If this is the main mechanism through which AWS result in a decrease in the prevalence of alcohol consumption among pregnant women, we would expect the effect to be the same across all women regardless of whether they have experienced a pregnancy before.

In an attempt to understand how AWS may change behavior, I divide the sample of births in the NVS data into two groups by birth order: first-born children and subsequent births. Then, I estimate equation 4.1 separately for the two groups to examine whether AWS have a differential impact on mothers' alcohol consumption during pregnancy depending on whether it is a first pregnancy or a subsequent pregnancy. The point estimates for AWS given in Table 6 indicate a larger and more statistically significant change in alcohol consumption associated with AWS among first-time mothers. This suggests that AWS may have an impact on alcohol consumption among pregnant women through the information presented on the signs, and the associated change in beliefs about the risks of drinking while pregnant.

TABLE 6. Alcohol warning signs laws and drinking during pregnancy by birth order

	First Births		Subsequent Births	
AWS	-0.00288**	-0.00220**	-0.00247*	-0.00139
	[0.00135]	[0.00078]	[0.00127]	[0.00086]
N	6,724,563	6,724,563	13,836,140	13,836,140
R^2	0.0100	0.0100	0.0160	0.0160
Mean	0.013	0.013	0.0161	0.0161
Std. Dev.	0.113	0.113	0.126	0.126
Year FE	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes
State-specific trends	Linear	Quadratic	Linear	Quadratic

Robust standard errors in parentheses, clustered at state level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

If there is a larger reduction in alcohol use among first-time mothers associated with AWS, and if drinking alcohol while pregnant results in poorer health at birth for the child, then we expect to see a larger improvement in birth outcomes among first-born babies. Table 7 presents the estimation results for birth outcomes by birth order. The point estimates for AWS for first-born babies are larger (in absolute value) and more statistically significant compared to the point estimates for subsequent births. These findings may imply that AWS may be associated with a larger reduction in the prevalence of inferior birth outcomes among first-born babies, and are consistent with our expectations. These findings may also be considered as a validation of my empirical strategy and the findings on birth outcomes presented in the previous section.

Effects on Other Outcomes

As discussed earlier, FAS is the most important adverse impact that prenatal alcohol exposure may have on a newborn. The birth certificate data includes information about whether the newborn was diagnosed with FAS at birth. Using an indicator for this diagnosis as the outcome variable in equation (1), I find that the coefficient estimate for the effect of AWS laws on the chance of the child being diagnosed with FAS is negative but not statistically significant. (See the first panel in Appendix Table 25.) This failure to detect any significant change in FAS may be a consequence of the fact that FAS is hard to discern at birth, and is thus underreported on the birth certificates (Martin et al., 2003).

Another standard measure of health at birth is the child's 5-minute Apgar score. The Apgar is a quick test performed on a newborn by a health practitioner during the first five minutes after birth. It is designed to evaluate the child's physical condition in terms of breathing effort, heart rate, muscle tone, reflexes, and skin color. Each category is scored, depending on the observed condition, on a scale of zero to two where two indicates perfectly healthy, and the total Apgar score out of ten is recorded. Using an indicator for low Apgar score as the dependent variable in the specification given in equation (1), where, following other literature, low Apgar score is defined as total Apgar score lower than seven, I find that AWS

TABLE 7. Whether (1) had low birth weight, (2) had very low birth weight, (3) was pre-term, (4) was very pre-term by birth order

	First Births				Subsequent Births			
	Low Birth Weight	Very Low Birth Weight	Pre-term	Very pre-term	Low Weight	Very Low Birth Weight	Pre-term	Very pre-term
AWS	-0.0007	-0.0002	-0.0009	-0.0006*	-0.0007	-0.0004	-0.0002	-0.0003
	[0.0008]	[0.0003]	[0.0015]	[0.0003]	[0.0010]	[0.0003]	[0.0016]	[0.0003]
N	15,294,861	15,294,861	13,696,977	13,696,977	31,271,641	31,271,641	27,316,749	27,316,749
R^2	0.01	0.005	0.008	0.005	0.014	0.004	0.013	0.005
Mean	0.0738	0.0138	0.0981	0.016	0.0672	0.0117	0.107	0.0158
Std. Dev.	0.261	0.117	0.297	0.126	0.25	0.107	0.31	0.125
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific trends	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic

Robust standard errors in parentheses, clustered at state level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

laws have no effect on the chance of newborn having a low Apgar score. (See panel (2) of Appendix Table 25.)

Finally, it can be noted that smoking during pregnancy is known to be negatively correlated with weight and gestational age at birth. One mechanism through which AWS laws could have an impact on birth outcomes could be that AWS laws may result in changes in maternal smoking behavior. If smoking and drinking are complements, then AWS laws may decrease smoking at the same time they decrease alcohol use. If that is the case, any change observed in birth outcomes might also be a result of a change in smoking behavior rather than simply a change in drinking. However, using an indicator for maternal smoking in equation (1) as the outcome variable, the estimates of β indicate that AWS laws do not result in a decrease in smoking during pregnancy. (See panel (3) in Appendix Table 25.)

Investigation of Threats to Identification and Additional Robustness Checks

One concern about using the variation in timing of a policy change across states as an identification strategy is that the adoption of the policy (or the timing of it) might be endogenous to the outcome. If states adopt AWS laws in response to an increase in the prevalence of drinking during pregnancy, then the estimated effect of AWS laws on alcohol consumption among pregnant women may be biased. To test whether the assumption that the timing of AWS laws is exogenous to alcohol use among pregnant women, I add lags and leads of the AWS indicator to the model. The results presented in Table 8 indicate that the lead terms are not statistically significant. This implies that the adoption of AWS laws was not systematically preceded by changes in drinking behavior among pregnant women.

TABLE 8. Adding lags and leads of AWS indicator

	(1)	(2)
3 years before AWS Law	-0.00149	-0.00066
	[0.00114]	[0.00061]
2 years before AWS Law	-0.00064	-0.00131
	[0.00122]	[0.00094]
1 year before AWS Law	-0.00142	-0.00171
	[0.00090]	[0.00116]
Year of AWS Law change	-0.00260**	-0.00192
	[0.00118]	[0.00137]
1 year after AWS Law	-0.00466***	-0.00314
	[0.00139]	[0.00193]
2 years after AWS Law	-0.00441**	-0.00224
	[0.00169]	[0.00254]
3+ years after AWS Law	-0.00314	0.00082
	[0.00246]	[0.00372]
N	21,427,399	21,427,399
R^2	0.013	0.013
Mean	0.0148	0.0148
Std. Dev.	0.121	0.121
Year FE	Yes	Yes
State FE	Yes	Yes
Covariates	Yes	Yes
State-specific trends	Linear	Quadratic

Robust standard errors in parentheses, clustered at state level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

As discussed earlier, the BRFSS data indicate statistically significant decline in drinking and binge drinking among pregnant women associated with AWS laws when I use the model given in equation (2). This specification defines pregnant women as the treatment group and non-pregnant women of child bearing age as the control group, and examines the differences in drinking behavior of the two group in response to AWS laws. I check the validity of this specification by performing a falsification test which uses men of age 18 to 44 as the treatment group against the same control group. Presumably, neither men nor non-pregnant women change behavior in response to AWS laws. Therefore, the results should indicate that AWS laws have no effect. Looking at Table 9, the coefficient estimate for β is in fact statistically insignificant, supporting the validity of the results presented earlier.

TABLE 9. Alcohol warning signs laws and alcohol consumption and binge drinking - BRFSS Falsification tests

	(1) Drinking			(2) Binge drinking		
Men*AWS	-0.00187	-0.00179	-0.00102	-0.00907	-0.00893	-0.00881
	[0.01272]	[0.01297]	[0.01304]	[0.01575]	[0.01582]	[0.01576]
Men	0.1273***	0.1272***	0.1268***	0.1721***	0.1719***	0.1719***
	[0.01518]	[0.01538]	[0.01544]	[0.01605]	[0.01612]	[0.01607]
AWS	-0.01623	-0.01858		0.00182	0.00047	
	[0.01653]	[0.01976]		[0.00815]	[0.00915]	
N	748,048	748,048	748,048	741,440	741,440	741,440
R^2	0.097	0.097	0.101	0.084	0.084	0.086
Mean	0.584	0.584	0.584	0.188	0.188	0.188
Std. Dev.	0.493	0.493	0.493	0.39	0.39	0.39
Year FE	Yes	Yes	No	Yes	Yes	No
State FE	Yes	Yes	No	Yes	Yes	No
State-by-year FE	No	No	Yes	No	No	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
State-specific trends	Linear	Quadratic	None	Linear	Quadratic	None

Sample weights provided in BRFSS data are used. Robust standard errors in parentheses, clustered at state level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Finally, as noted earlier, the time period used in investigation of the effects of AWS laws on birth outcomes is expanded to 1980-2010 to include more observations on earlier years relative to the time period for which data on alcohol use is available. However, the findings on the effect of AWS laws on very low birth weight and very pre-term birth presented in the previous section are robust to restricting the time window to both 1989-2006 and 1985-2010, to match the time window used in the alcohol consumption regressions with the NVS data and the BRFSS data. (See Appendix Table 26.)

Conclusion

To date, 23 states and the District of Columbia have adopted laws that require alcohol retailers to post signs that warn against the risks of drinking during pregnancy. This study examines the effect of point-of-sale alcohol warning signs (AWS) on prenatal alcohol consumption and on birth outcomes using the variation in timing of state-level AWS legislation. The findings of this study using the National Vital Statistics (NVS) data indicate that AWS laws are associated with an 11% decrease in alcohol consumption during pregnancy. This result is supported by findings obtained using data from the Behavioral Risk Factor Surveillance System (BRFSS) in a model that uses the variation in the pregnancy status of women. The impact of AWS laws implied by the BRFSS data is larger than the impact implied by the NVS data.

In a second set of models, I use the change in drinking behavior among pregnant women in response to AWS laws (which are plausibly exogenous to birth outcomes) to identify the effects of prenatal alcohol exposure on infant health. The results for these reduced form specifications using the NVS data indicate that AWS laws are related to birth outcomes. In particular, AWS laws are associated with a decrease in the chance of the newborn having very low birth weight (birth weight less than 1500 grams) and being born very pre-term (gestational age less than

32 weeks). These findings suggest that there may be a direct impact of prenatal alcohol exposure on both weight and gestational age at birth.

The change in birth outcomes associated with AWS laws is small, representing about 3% of the mean for very low birth weight and very premature births. The magnitude and statistical significance of the estimated coefficients on the AWS indicator, and the impact that these estimates imply in percentage terms, are consistent across dependent variables that indicate birth weight less than a variety of possible birth weight thresholds ranging from 1000 grams up to 1700 grams. Similarly, using different gestational age cut-offs similar to the one commonly used for very pre-term birth produces similar coefficient estimates for the effect of AWS laws. These findings imply that the negative effect of AWS laws on the chance of a child having very low birth weight and being born very pre-term are not merely a result of fortuitous arbitrary choice of birth weight and gestational age thresholds.

I find that AWS laws have no statistically discernible effect on whether the newborn is diagnosed with fetal alcohol syndrome. This result may be driven by the fact that FAS is rarely diagnosed at birth and recorded in birth certificates. AWS laws also do not appear to be related to Apgar scores or whether the mother smoked while pregnant.

In investigating the effectiveness of AWS laws in reducing prenatal alcohol use and in using the variation in timing of AWS laws to identify the causal relationship between prenatal alcohol exposure and birth outcomes, one assumption is that the timing of AWS laws is exogenous to the changes in the prevalence of drinking among pregnant women. The validity of this assumption, and thus my identification strategy, is supported by the data. Moreover, the findings in the BRFSS data is supported by the results of a falsification test which indicate that, as expected, there is no change in drinking behavior of men relative non-pregnant women in response to AWS laws.

This study thus finds evidence that AWS laws may be an effective and relatively low-cost policy tool for reducing alcohol use among pregnant women. Given that the reduction of prenatal alcohol use had been one of the most important public health policy goals over the last few decades, these findings suggest that the posting of warning signs may indeed help to achieve this goal.

CHAPTER III

HEAT WAVES: EFFECTS ON FERTILITY DECISIONS AND PREGNANCY OUTCOMES

The empirical work presented in this chapter, including data cleaning, analysis, and presentation of results, was done by me, and excerpt included was also written by me. Trudy Ann Cameron provided assistance in developing empirical models in the analysis, and invaluable editorial assistance in writing.

Introduction

The latest assessment report by the Inter-governmental Panel on Climate Change (IPCC) states that increases in greenhouse gases in the atmosphere, as well as modifications to land use and land cover over the last 50 years, have led to increases in the frequency and intensity of extreme weather events (Solomon et al., 2007). Given the increasing confidence, expressed in that report (and others), in predictions that climate change will lead to further changes in the intensity and duration of extreme heat events, the negative impact of such weather conditions on human health is a major concern. In fact, the potential adverse health effects of climate change appear to be one of the strongest motivating factors for policy actions related to climate change. However, the inadequate state of existing knowledge in this area is often cited as one of the key constraints on the implementation of these policies (Pachauri and Reisinger, 2007). The IPCC explicitly calls for further research on the link between climate change and human health (Metz et al., 2007). Likewise, the World Health Organization considers investments in research on the potential health impacts of climate change and possible response options as an essential part of adaptation plans (Scheraga et al., 2003).

This study contributes to the literature that seeks to identify the extent of the potential adverse human health effects of climate change. Specifically, we investigate the effects of heat waves on health risks for expectant mothers and on birth outcomes for babies born to mothers who have been exposed to such events while pregnant or during the period just prior to conception. We offer three main innovations relative to earlier work. First, we emphasize the potential importance of systematic selection. We start with an investigation of the potential impact of heat waves on fertility decisions to examine whether exposure to extreme heat leads to selection into (or out of) fertility, or to any measurable changes in the socio-demographic characteristics of mothers giving birth. If there are differential fertility responses to heat waves by different socio-demographic groups, any observed change in birth outcomes might be a result of common or differential changes in fertility or of systematic selection. Using a monthly panel of all U.S. counties, we find that heat waves appear not to be systematically associated with changes in birth rates, where birth rate is defined as the total number of births in a given county-month per thousand women of reproductive age. Also, heat waves do not appear to result in any changes in the racial and educational composition of the set of new mothers, which implies that there is no evidence of a significant differential fertility response or endogenous selection into fertility associated with heat waves.

Second, we consider all heat waves that have occurred in the U.S. from 1989 through 2008, and investigate their adverse effects on the entire population of U.S. births over the same time period. The existing studies which concern the link between extreme weather events and birth outcomes (discussed in the next section) tend to consider the impact of a specific event, e.g. Hurricane Katrina, or a given type of event in a specific geography, e.g. storms in Texas, or to use a time series of historical data on the overall general population, e.g. data on all births from 1968 through 1988. Using more recent data on the entire population of births, disaggregated to the county level, may offer a more appropriate estimate of the potential impacts of extreme heat today and in the future.

Third, we note that birth weight and gestational age seem to be the standard measures of health at birth, and these measures have been shown to be linked to the individuals future health, education and income (Currie, 2009). However, in addition to these widely used metrics, we investigate several other measures of pregnancy outcomes, for both the newborn and the mother.

For newborns, we consider the potential impact of heat waves on the risk of occurrence of three types of abnormal conditions (including fetal distress, assisted breathing on a ventilator for more than 30 minutes, and meconium aspiration syndrome). These abnormal conditions may also be linked to subsequent health complications in early childhood or later in life, and thus may also pose a potentially important source of social costs associated with heat waves.

Heat waves certainly impose psychological or emotional discomforts upon many expectant mothers, but these extreme weather events may have real physiological impacts on these women as well, with consequences that are potentially harmful for the fetus. In fact, findings in epidemiology literature (discussed in more detail in the next section) suggest that pregnant women may be at a greater risk for health complications related to heat stress. A better assessment of the nature and magnitude of the impacts of extreme heat on pregnant women is important to the question of how to enhance the effectiveness of climate change adaptation efforts. We consider the association between exposure to heat waves during pregnancy and the risk of experiencing pregnancy-related health conditions for the expectant mothers including pregnancy-associated hypertension, eclampsia, incompetent cervix and uterine bleeding.

In sum, then, we investigate the impact of heat waves on (1) the fraction of births with low birth weight, and (2) the average gestational age of all births in a county. But we also explore the impact of heat waves on (3) the fraction of newborns with any of the above-mentioned set of abnormal conditions and (4) the fraction of expectant mothers experiencing an of the above-mentioned set of health risks during pregnancy (all controlling for a selection of socio-demographic characteristics, time-invariant county characteristics, seasonality of birth outcomes, and state-specific changes in birth outcomes over time). Heat waves during the second trimester of the pregnancy lead to a very small decrease in average gestational age, although there is no statistically significant impact on the fraction of births with low birth weight. However, we find that heat waves do increase the fraction of newborns with abnormal conditions and the fraction of mothers with a pregnancy-related health condition. In falsification tests, reassuringly, we find that experiencing a heat wave during the three months after birth has no discernible effect on any of the birth outcome variables that we consider. This test supports the validity of our identification strategy.

The rest of the paper proceeds as follows. Section 2 provides a brief background and a more detailed sketch of the related literature on extreme weather events and pregnancy outcomes. Section 3 describes the data. In Section 4, the empirical models and the estimation results are presented and discussed. Section 5 concludes.

Background

It is a well-established result in both the medical and economic literatures that there is an association between poor birth outcomes and subsequently worse socioeconomic and health-related outcomes for these individuals later in life (see Currie, 2009; Almond and Currie, 2011a; Almond and Currie, 2011b). Fetal development is considered one of the most important factors in a child's later development, and the health and developmental difficulties experienced by many low-birth-weight infants can impose large costs on society (Almond et al., 2005). Moreover, as supported by empirical evidence, the intergenerational transmission of poor infant health at birth also represents an important source of social costs (Currie, 2011). Therefore, social interventions designed to mitigate harm might optimally be targeted towards pregnant women and/or women of child-bearing age in addition to young children (Almond and Currie, 2011a). The same rationale might hold for mitigating risks to these populations from severe weather events related to climate change.

There is a body of epidemiological literature investigating the impact of external shocks on measures of birth outcomes. The external events considered in these studies include earthquakes, the 9/11 attack and other terrorist attacks, and nuclear reactor and toxic waste accidents (see Harville et al., 2010a for a review of this literature). The results in these studies seem to support the contention that experiencing stress from a disaster during pregnancy, even in the absence of a direct exposure or immediate personal impact, can have an adverse effect on pregnancy outcomes.

The psychological and social impacts on pregnant women produced by these various types of natural and anthropogenic calamities may be similar to those caused by extreme weather events. There are studies indicating that women who had been pregnant during or shortly after Hurricane Katrina were at increased risk of mental health problems such as depression and post-traumatic stress disorder (Ehrlich et al., 2010; Harville et al., 2009), and that Hurricane Katrina was associated with an increase in the occurrence of pre-term and low-birth-weight births (Xiong et al., 2008; Harville et al., 2010b). Similarly, Zahran et al. (2010) find that maternal exposure to Hurricane Andrew resulted in higher risks of fetal distress in Florida, even after adjusting for known risk factors.

Zahran et al. (2010) argue that maternal stress, and the associated changes in the maternal vascular system, may be an explanation for fetal distress, which is characterized by signs of oxygen deficiency in fetal tissues. They explain that maternal stresswhether it is a physiological stress (such as maternal under-nutrition or malnutrition) or a psychological and emotional stress (linked to mothers depression, anxiety, or trauma)may lead to the release of stress hormones such as cortisol. These hormones activate a number of physiological systems that prepare the body for action and respond to stress by drawing blood from other processes, such as reproduction, which are nonessential to immediate action. This can potentially draw vital nutrients and oxygen away from the developing fetus. These authors point out that in cases of excessive stress and resultant high levels of maternal cortisol, when infants are unable to convert cortisol to its inactive forms, high levels of circulating cortisol in the fetus itself can lead directly to a fetal stress response, which in effect may lead to excessive oxygen consumption by the fetus and fetal distress as well as other important adverse birth outcomes.

Lee (2014) finds that the adverse impacts of maternal stress are transmitted to the health of the next generation. He investigates the intergenerational influences of maternal stress from the Kwangju uprising in South Korea, and finds that mothers in utero exposure to maternal stress diminishes the offspring birth weight and length of gestation, and increases the risk of low birth weight and preterm birth.

In a recent study, Currie and Rossin-Slater (2012) analyze the effects of severe storms and hurricanes on birth outcomes in Texas over the period 1996 to 2008. They find little evidence of a relationship between exposure to a hurricane during pregnancy and gestation or birth weight, but their findings indicate that mothers living close to a hurricane path during pregnancy were more likely to have some kind of complication during delivery and more likely to have a newborn with abnormal conditions. The abnormal conditions upon which they focusincluding assisted ventilation for more than 30 minutes and meconium aspiration syndromereflect fetal stress.

The events mentioned above, including hurricanes and storms, are typically thought to affect birth outcomes through direct injuries to the mother or by aggravating maternal stress. Heat waves, on the other hand, may affect human health through a variety of different mechanisms. Extreme heat may increase the risks of water-, food- and vector-borne illnesses, and mental, respiratory and diarrheal illnesses. More importantly, exposure to high temperatures increases the risk of acute and chronic health conditions associated with heat stress. These conditions include heat exhaustion, heat stroke, heat rash and heat cramps.

Pregnant women and fetuses might be affected more severely by extreme temperatures. As mentioned in the introduction, findings in the epidemiology literature (see Strand et al., 2011 for a review) suggest that pregnant women may be at a greater risk of heat stress. As a result of normal weight gain and the nature of fat disposition during pregnancy, core body temperatures and heat production tend to be higher among pregnant women. Moreover, disturbed sleep during pregnancy due to heat may also be a significant risk factor for adverse pregnancy outcomes (Okun et al., 2009).

Several recent studies have examined the relationship between exposure to hot weather and birth outcomes in specific geographic regions. Some examples include original research based on 300,000 births in two German states is reported in Wolf and Armstrong (2012), who find weak evidence for an association between season of conception, season of birth or ambient outdoor temperatures and term low birth weight or preterm birth. However these effects are not consistent across the two states.

In contrast, short-term exposure to high and low temperatures and air pollution on preterm births are studied by Schifano et al. (2013) for Rome during 2001-2010. Sociodemographic and clinical risk factors are interacted with these exposures and reveal susceptible subgroups of women. A statistically significant 1.9% increase in daily preterm births per 1 degree C in the two days preceding delivery is estimated for the warm season. A 19% increase in preterm births was observed during heat waves.

Another single-city analysis is provided by Wang et al. (2013) for Brisbane, Australia during 2000-2010. Using proportional hazards models with time-dependent regressors, these authors find that heat waves are significantly associated with preterm births. Currie and Schwandt (2013) innovate by using a sample of siblings to net out unobserved maternal heterogeneity and find a sharp trough in gestations length for babies conceived in May, corresponding to a 10% increase in prematurity. They also find that birth weight tends to be higher by 8-9 grams for summer conceptions.

A number of relevant review articles are also available. Strand et al. (2011) assemble the epidemiological evidence on seasonality in birth outcomes as well as the effects of prenatal exposure to extreme temperatures. Across twenty studies, they report that most find peaks of preterm birth, stillbirth, and low birth weight in winter, summer, or both. They note that the adverse effect of high temperatures appears to be stronger for birth weight than for preterm birth, and they call for more research "to clarify whether high temperatures have a causal effect on fetal health."

The effects of meteorological conditions on pregnancy outcomes are examined in Laaidi et al. (2011), who review 134 articles on the subjects of preterm birth, birth weight, and preeclampsia across many different countries. They note seasonality in these outcomes, explained in part by temperature variations and sometimes by atmospheric pressure, but these variations differ in amplitude and periodicity across countries. Correlations between environmental conditions, cultural backgrounds, and socioeconomic factors make it difficult to discern the incremental contributions of temperatures alone.

Carolan-Olah and Frankowska (2014) provide a very recent review of over 150 papers and conclude that the weight of the evidence supports an association between high environmental temperatures and preterm births. Rates of preterm birth appear to be linked to heat stress, which may be experienced during extreme heat or following a sudden rise in temperature. Beltran et al. (2013) review 35, 28, and 27 studies concerning hypertensive disorders of pregnancy (including eclampsia), gestation length, and birth weight as a function of meteorology. They find that the relative risk of eclampsia is the highest for women who give birth during the month of December (i.e. women who have been in the second trimester of pregnancy during summer months). They also report decreases in gestation length associated with heat, but note that birth weights are lower for deliveries in winter months and in summer months. They call for further etiological research concerning the relationships between meteorology and adverse pregnancy outcomes.

There appear to be two studies in the economic literature that explore the effects of heat on birth outcomes. In the first study, Deschênes et al. (2009) use near-universal U.S. data on births for the period 1972 through 1988 to examine the effects on birth weights of ambient outdoor temperatures during gestation. Specifically, they aggregate the station-level average daily temperature data at the county level, and use the number of days during each trimester of the pregnancy in which a countys average daily temperature falls into each of the five temperature bins (from less than 25F to greater than 85F) as the key regressors. Their findings indicate that experiencing high temperatures during the second and the third trimester of the pregnancy is associated with slightly lower birth weights.

The other study is by Simeonova (2011), who investigates the effects of exposure to several types of natural disasters on gestational age at birth and birth weight. She combines the U.S. natality data for the twenty-year period from 1968 to 1988, aggregated to the county level, with climate data on extreme weather events such as thunderstorms, floods and heat. She then estimates the effects of there having been at least one such event in a county on two outcome variables: the county average of birth weights and county average gestational age. Her findings for heat waves indicate that exposure to a heat wave during the second trimester of the pregnancy is associated with lower birth weight, but heat waves during the third trimester of the pregnancy are associated with longer gestation. She does not speculate upon a mechanism that could explain this unexpected effect in the third trimester.

We innovate by considering a county/year panel advanced by twenty years beyond the time frame covered in these earlier works in economics. We use 1989-2008 rather than 1968-1988. An update to the time dimension of the analysis is important for several reasons. First, until the 1980s there are several states that do not report gestational age on birth certificates. Also, in the later time period, there have been more frequent and widespread heat waves. The number of counties that are affected by heat waves is in fact more than 50% higher during 1989-2008 compared to 1968-1988. Finally, in the last two decades, air conditioning might have become more widespread in both residential and commercial buildings compared to earlier years. Therefore, the results using the more recent data might offer a more relevant estimate of the potential impact of extreme heat today and in the future.

Another contribution of this study is that we consider the potential impact of heat waves on fertility decisions in the general population (and among different socio-demographic groups) as a strategy designed to address potential composition bias. Without an appropriate analysis of the effects of heat waves on fertility decisions, it would not be clear whether any implied association between exposure to heat waves and birth outcomes is real, or merely an artifact of selection/composition bias.

Finally, in addition to widely used metrics such as birth weight and gestational age, we investigate the potential impact of heat waves on abnormal conditions in newborns that are associated with maternal stress. We also consider the association between exposure to heat waves during pregnancy and the risk of experiencing a pregnancy-related health condition for the expectant mothers. The health conditions that we consider gestational hypertension, eclampsia, incompetent cervix and uterine bleeding are health conditions that mothers may experience after they become pregnant. There are two important reasons for analyzing the health complications of the mother during pregnancy. First, the conditions we consider have been shown to be associated for the mother with further health complications later in life, and even premature death (although the association may not be causal). For example, women with a history of hypertension during pregnancy are more likely to suffer from diseases related to hypertension later in life, and women with pre-eclampsia during pregnancy are at a greater risk of having cardiovascular diseases and of dying from stroke or ischemic heart disease (see Bellamy et al., 2007, for the review of this literature).[1]

Second, any factor that has an adverse impact on the mothers health during pregnancy potentially affects the fetus and thus the childs future well-being. For example, external shocks to a mothers health during pregnancy as a result of an influenza epidemic have been shown to be associated with inferior future health, education and labor market outcomes for the child (Almond and Mazumder, 2005; Almond, 2006). Although the long-term effects of the specific pregnancy-related health complications that are considered in this study and childs future health and education outcomes are largely unknown, there is certainly evidence in epidemiology literature about an association between hypertension during

[1]Wilson et al. (2003) classify hypertensive problems during pregnancy into four categories: chronic (pre-existing) hypertension, gestational (transient) hypertension, pre-eclampsia/eclampsia, and pre-eclampsia superimposed on chronic hypertension, where they define pre-eclampsia as gestational hypertension plus proteinuria of $\geq$0.3g/24 hours, and eclampsia as convulsions occurring in the presence of pre-eclampsia.

pregnancy and lower birth weight and shorter gestation (e.g. Ananth et al., 1995), and between uterine bleeding and pre-term delivery (e.g. Yang and Savitz, 2001; Yang et al., 2004).

Data

Our data on birth outcomes are drawn from the National Vital Statistics System for the period 1989-2008. The Natality data consist of all births registered in the U.S., and include information on each individual newborn, such as gender, month of birth, and birth weight, as well as information on the mother, including age, race, marital status and education. We employ the restricted-use version of the data, which identifies each mothers county of residence. We aggregate the natality data on singleton births to the county level so that the unit of observation is a county-month.[2]

To consider the potential impact of heat waves on fertility decisions, we calculate the birth rate in each county by dividing the total number of births in a given county-month by the number of women aged 15-44 in that county (in thousands). The population data are from Surveillance Epidemiology and End Results (SEER), which provides annual county-level population estimates (by gender and age) for each county.

Finally, extreme weather data are available from the Spatial Hazard Events and Losses Database for the U.S. (SHELDUS), which provides county-level spatial resolution for all heat waves that have occurred in the U.S. and have

[2]Hawaii and Alaska are excluded. County codes that have changed over time are adjusted. The reason for the county-level aggregation is to overcome computational issues. Specifically, to take advantage of the geographic variation in the heat wave occurrences, we use the entire population of births in the continental U.S. The number of observations available in the individual-level data, together with a specification that involves large number of regressors, necessitates aggregation for computational tractability in finite time.

resulted in at least $50,000 worth of damage or one fatality (SHELDUS, 2013). In the data, a heat wave is defined as an unusually hot period whenever the heat index, which combines the temperature with relative humidity, meets or exceeds locally/regionally established advisory thresholds. Except for the years 1989 through 1994, the SHELDUS data set also includes other events where the total damage is less than $50,000 and when there are no fatalities. However, we exclude these additional events during the period 1995-2008 to make the data on heat waves conform across all years. [3]

The key independent variables used in all of the specifications throughout the paper are county- level indicators for the occurrence of a heat wave in a given time period. The time periods are constructed relative to the month of birth as shown in Figure 6. The heat wave indicator for the time period that corresponds to the third trimester of pregnancies in a given county, for instance, is equal to one if the county experienced a heat wave in the birth month or in the three-month period prior to the birth month. Similarly, the heat wave indicator for the second trimester is equal to one if there was heat wave in the county four to six months prior to the birth month. As a falsification test, we include one three-month period lead term in all of our specifications (under the logic that events taking place after a birth should have no effect on the outcome of that birth).

[3] The monetary threshold of $50,000 for total damage is not adjusted for inflation over time. The decline in the value of the monetary threshold for damage in real terms may be one of the reasons for why we observe more frequent and widespread heat events in the data in more recent years to the extent that monetary threshold is relevant for heat waves.

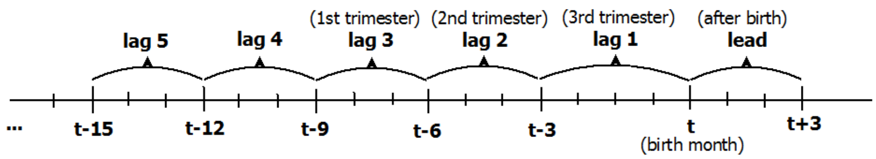

FIGURE 6. Time-aggregation of county level heat wave indicators and definition of trimesters for the purposes of our analysis

Results

Effects of Heat Waves on Fertility and Composition of The Set of Mothers

Before considering either the effects of heat waves on conventional birth-outcome variables or their effects on our newer categories of pregnancy outcomes, we first consider the potential impacts of heat waves on fertility decisions and potential selection into fertility by groups that have historically displayed higher or lower risks of having babies with poor birth outcomes. Heat waves and birth rates (or the educational or racial composition of the set of new mothers) may be linked in two ways: (1) If heat waves lead to miscarriages or abortions in the overall population, then we might observe a decrease in the overall birth rate within a county in response to a heat wave that has occurred within the last nine months in that county. Similarly, if heat waves result in more or fewer miscarriages or abortions in a specific racial group (or in a group of mothers with a certain level education), then there might be a decrease or increase in the fraction of mothers in that racial (or educational) group giving birth in a given county- month in response to a heat wave occurring within the past nine months. (2) Heat waves might also be associated with conception decisions in the overall population or in certain socio-demographic groups. If women (or a subset of women) choose to postpone becoming pregnant in the first place, in response to a heat wave, we could observe a decrease in the birth rate (or a change in composition of mothers) in response to a heat wave that has occurred even more than nine months before the month for which the birth rate is calculated.

Our reduced form specifications for the birth rate reveal how the number of births per thousand women of child-bearing age in a given county-month varies systematically with the occurrence of heat waves in the past two years. The indicators for heat waves follow the strategy for time-aggregation described previously. To account for time-invariant county characteristics that are potentially correlated with both fertility decisions and the effects of heat waves, we control for county fixed effects. Finally, we include month fixed effects and state-by-year fixed effects to account for the typical seasonality in birth rates and trends or other changes in fertility over the years, allowing these changes to be different in each state.

The regression equation is:

$$
\begin{aligned}
BirthRate_{ct} \quad = & \left[\begin{array}{l}
\beta_{postbirth\_qtr} 1(H_{c,t+3} > 0 \text{ or } H_{c,t+2} > 0 \text{ or } H_{c,t+1} > 0) \\
+\beta_{trimes3} 1(H_{c,t} > 0 \text{ or } H_{c,t-1} > 0 \text{ or } H_{c,t-2} > 0 \text{ or } H_{c,t-3} > 0) \\
+\beta_{trimes2} 1(H_{c,t-4} > 0 \text{ or } H_{c,t-5} > 0 \text{ or } H_{c,t-6} > 0) \\
+\beta_{trimes1} 1(H_{c,t-7} > 0 \text{ or } H_{c,t-8} > 0 \text{ or } H_{c,t-9} > 0) \\
+\beta_{preconcep\_qtr1} 1(H_{c,t-10} > 0 \text{ or } H_{c,t-11} > 0 \text{ or } H_{c,t-12} > 0) \\
+ ... + \beta_{preconcep\_qtr5} 1(H_{c,t-22} > 0 \text{ or } H_{c,t-23} > 0 \text{ or } H_{c,t-24} > 0)
\end{array} \right] \\
+ & \quad \alpha_m + \alpha_{sy} + \alpha_c + \epsilon_{ct} \qquad (3.1)
\end{aligned}
$$

where the parameters α_m, α_{sy}, α_c are month fixed effects, state-by-year fixed effects and county fixed effects, and the effects of heat waves during different time intervals on birth rates in month t are given by the β parameters.

In Panel A of Table 10, we present our key estimation results for the effects of heat waves in the future (the falsification test) and the past (with up to two years of lags) on the birth rate in specific county- month. The first four coefficients and standard errors in vertical Panel A of Table 10 suggest that there is no association between heat waves during pregnancy and the associated prior fertility decisions, as should be the case since conception occurs typically in seven to nine months before the birth month. Our results also suggest that heat waves are not associated with miscarriages or abortions. The last five coefficients and standard errors imply that the heat waves are not associated with conception decisions. That is, the timing of the conception appears to be unrelated to the heat waves.

Although heat waves appear to be unrelated to overall birth rates, there might be differential fertility responses across different socio-demographic groups. To explore whether there is different selection into (or out of) fertility in response to heat waves for different socio-demographic groups, we examine how the racial and educational composition of mothers giving birth in a given county-month changes in response to heat waves. Vertical Panel B of Table 10 presents our estimates of the effects of heat waves on the racial composition of mothers giving birth in a given county-month using a specification analogous to equation 3.1. The outcome variables in this pair of equations are the fraction of births to white mothers and the fraction of births to black mothers. Our estimates suggest that heat waves are not associated with any statistically significant change in the racial composition of mothers, which suggests that there is minimal differential selection into fertility by race as a function of heat waves in the pre-pregnancy period.

There may also be differential fertility responses to heat waves for women who have different levels of education. Vertical Panel C of Table 10 presents the

TABLE 10. No statistically significant effect of heat waves on birth rate, racial and educational composition of mothers

	Panel A	Panel B		Panel C		
		Fraction of births to		Fraction of births to mothers with		
	Birth Rate	White mothers	Black mothers	Less than high sch.	High sch. or some coll.	College or more edu.
$\beta_{postbirth\_qtr}$	-0.0577	0.888	-0.689	-0.762	1.431	-0.669
	(0.125)	(0.743)	(0.632)	(1.278)	(1.587)	(1.239)
$\beta_{trimester3}$	0.0283	-0.668	-0.049	-0.179	0.522	-0.343
	(0.120)	(0.712)	(0.588)	(1.133)	(1.435)	(1.112)
$\beta_{trimester2}$	-0.125	-0.223	0.118	-0.130	0.581	-0.451
	(0.143)	(0.765)	(0.637)	(1.213)	(1.533)	(1.305)
$\beta_{trimester1}$	-0.203	-0.783	0.424	-1.177	0.721	0.456
	(0.161)	(0.807)	(0.678)	(1.357)	(1.687)	(1.431)
$\beta_{preconception\_qtr1}$	-0.128	-0.084	-0.637	-1.930	1.656	0.274
	(0.138)	(0.794)	(0.670)	(1.270)	(1.614)	(1.304)
$\beta_{preconception\_qtr2}$	-0.0952	0.568	-0.944	0.863	0.691	-1.554
	(0.148)	(0.823)	(0.679)	(1.240)	(1.612)	(1.290)
$\beta_{preconception\_qtr3}$	-0.167	-0.693	0.640	1.651	-0.323	-1.328
	(0.149)	(0.836)	(0.668)	(1.259)	(1.508)	(1.195)
$\beta_{preconception\_qtr4}$	-0.122	-1.303*	0.431	-0.256	-0.819	1.076
	(0.107)	(0.777)	(0.647)	(1.169)	(1.545)	(1.229)
$\beta_{preconception\_qtr5}$	-0.109	0.130	-0.682	-0.210	-0.195	0.405
	(0.095)	(0.764)	(0.605)	(1.166)	(1.469)	(1.154)
Observations	738,240	727,521	727,521	725,489	725,489	725,489
Number of counties	3,076	3,077	3,077	3,077	3,077	3,077

Notes: Robust standard errors in parentheses, clustered at the county level. All regressions include county fixed effects, month fixed effects, and state-by-year fixed effects. Birth rate is the total number of births in a county-month per thousand women of child-bearing age in that county. Fraction of births are calculated by dividing total number of births to mothers with the given characteristic in a given county-month by total number of births in thousand in that county.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

effects of heat waves on the mix of educational attainment among mothers where the outcome variables are the fraction of births to mothers with less than high school education, mothers with only high school or some college education, and mothers with a college degree or more. It appears that heat waves do not result in selection into fertility that differs by education either. The findings in Table 10 reassure us that any statistically detectable effects that heat waves may have on birth outcomes are unlikely to be simple artifacts of changes in the composition of the set of mothers.

Effects of Heat Waves on Birth Weight and Gestational Age

For our analysis of the effects of heat waves on birth outcomes, we first consider the effects of heat waves on the most commonly used birth outcome variables: birth weight and gestational age. We aggregate the sample of all singleton births to the county-month level so that the outcome variables are the number of births with low birth weight (per thousand), and the average gestational age of all births in a given county-month. The mean values for these outcome variables (and the other birth outcomes considered in the next sections) are listed in the first horizontal panel of Table 11.

The key independent variables in our specification are the indicators for heat waves during each three-month period, lagged up to one year before birth, which would correspond to each trimester of the pregnancy and the three-month period just prior to conception. Again, as a falsification test, we include one three-month period lead term, which indicates heat waves after birth.

It has been established empirically in previous literature that these two measures of birth outcomes can be associated with the socio-demographic

TABLE 11. Summary statistics for all outcome variables considered in this paper for 1989-2008*

Outcomes:	Mean	Std. Dev.	N (county-month)
Usual birth outcome metrics:			
Low birth weight	60.7	71.36	727,516
Average gestational age in weeks	38.97	0.84	725,662
Newborn abnormal conditions:			
Fetal distress	45.37	72.55	581,923
On a ventilator for more than 30 minutes	10.41	37.88	622,823
Meconium aspiration syndrome	2.44	16.91	623,006
Any of the three abnormal conditions	80.6	170.9	594,454
Maternal health conditions:			
Pregnancy-associated hypertension	43.91	66.06	723,942
Eclampsia	3.82	20.28	723,942
Incompetent cervix	2.44	16.39	623,093
Uterine bleeding	7.7	28.58	582,101
Any of the four health risks	129.5	259.7	623,435

Notes: Each variable, with the exception of average gestational age, indicate the number of babies or mothers per thousand with the condition in a given county-month. *Data on meconium aspiration syndrome, being on a ventilator for more than 30 minutes, fetal distress, incompetent cervix, and uterine bleeding are not available for the years 2007 and 2008. Therefore, any of the three abnormal conditions and any of the four health conditions also exclude 2007 and 2008.

characteristics of the mother such as race, education, age and marital status. Although it is reasonable to assume that when and where a heat wave occurs, and its severity, are random with respect to the characteristics of expectant mothers, the level at which mothers are affected by a heat wave might be determined by their socio-demographic characteristics. If so, failure to account for mothers socio-demographic characteristics in the regressions for maternal and neonatal outcomes would allow socio-demographic characteristics to confound the estimates of the effects of heat waves on these outcomes. The findings in the previous section suggest that the socio-demographic composition of the set of expectant mothers in a county is not changing systematically with heat waves. This enables us to control for these potentially confounding socio- demographic factors in the regressions to explain these two measures of birth outcomes. Specifically, we control for the fraction of births in a given county-month to black mothers and other non-white mothers, and the fraction of births to mothers with less than a high school education (omitted category), high school education, and college education. We also control for the fraction of mothers aged less than 18, 18- 22, 23-28 (omitted category), 29-34, and 35-and-over, the fraction of married mothers, the fraction of mothers who started prenatal care in the first trimester, the average number of prenatal visits, and the fraction of male babies.

As in our specifications used in the analysis of fertility decisions, we use county, month and state-by-year fixed effects in these outcome models. These fixed effects account for time-invariant county characteristics, the seasonality of birth outcomes, and any common state-level changes in birth outcomes over the years. Our generic outcome regression equation is:

$$
\begin{aligned}
BirthRate_{ct} \;&=\; \begin{bmatrix}
\beta_{postbirth\_qtr} 1(H_{c,t+3} > 0 \text{ or } H_{c,t+2} > 0 \text{ or } H_{c,t+1} > 0) \\
+\beta_{trimes3} 1(H_{c,t} > 0 \text{ or } H_{c,t-1} > 0 \text{ or } H_{c,t-2} > 0 \text{ or } H_{c,t-3} > 0) \\
+\beta_{trimes2} 1(H_{c,t-4} > 0 \text{ or } H_{c,t-5} > 0 \text{ or } H_{c,t-6} > 0) \\
+\beta_{trimes1} 1(H_{c,t-7} > 0 \text{ or } H_{c,t-8} > 0 \text{ or } H_{c,t-9} > 0) \\
+\beta_{preconcep\_qtr1} 1(H_{c,t-10} > 0 \text{ or } H_{c,t-11} > 0 \text{ or } H_{c,t-12} > 0)
\end{bmatrix} \\
&+\; X_{ct}\gamma + \alpha_m + \alpha_{sy} + \alpha_c + \epsilon_{ct} \qquad (3.2)
\end{aligned}
$$

where Y_{ct} is one of the newborn outcome variables for county c, year-month t. X_{ct} is the vector of covariates mentioned above, and α_m, α_{sy}, and α_c are month fixed effects, state-by-year fixed effects and county fixed effects. The effects of heat waves during different time intervals relative to birth are again given by βs.

Table 12 shows the effects of a heat wave in a county on the two most-common birth outcome variables: (1) the fraction of births with low birth weight and (2) average gestational age. The estimates suggest that exposure to a heat wave during or before pregnancy has no statistically significant effect on the fraction of births with low birth weight. However, a heat wave during the second trimester of the pregnancy is associated with a statistically significant but tiny decrease in average gestational age. The point estimate for the second trimester can be interpreted as follows: A heat wave during the time period that corresponds to the second trimester of the pregnancy is associated with a little over a three-hour (1.9% of a week) decrease in average gestational age.

It is worth pointing out that this is the average effect on gestational age of all births that have occurred in a given county-month. Expectant mothers living in the same county might have been exposed to the effects of heat waves at varying levels,

TABLE 12. Usual birth outcome metrics: Effects of heat waves on the number of babies (per thousand) born with low birth weight and on average gestational age in weeks (key coefficients only)

	Fraction with low birth weight	Average gestational age
$\beta_{postbirth\_qtr}$	0.508	0.000
	(0.740)	(0.008)
$\beta_{trimester3}$	-0.266	-0.009
	(0.581)	(0.008)
$\beta_{trimester2}$	-0.877	-0.019**
	(0.639)	(0.008)
$\beta_{trimester1}$	0.455	-0.006
	(0.690)	(0.008)
$\beta_{preconception\_qtr1}$	-0.117	-0.009
	(0.647)	(0.008)
Observations	725,090	723,440
Number of counties	3,077	3,077

Notes: Robust standard errors in parentheses, clustered at the county level. All regressions include controls, county fixed effects, month fixed effects, and state- by-year fixed effects.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

and the estimated effect is the average across all mothers living in the same county. Although the effects of heat waves on average gestational age appear to be very small, heat waves may have a substantial impact on gestational age distribution within a county-month by, for instance, changing the variance of the skewness of the distribution but leaving the mean gestational age relatively unchanged. In an attempt to understand potential impact of heat waves on gestational age distribution, we used the 5th and 10th percentiles of gestational age in each county-month (rather than the mean) as the outcome variables in the specification discussed above. However, the results did not reveal any conclusive impact of heat waves on these lower quantiles of the gestational age distribution.

Effects of Heat Waves on Newborn Abnormal Conditions

We also use the specification given in equation 3.2 to analyze the effects of heat waves on abnormal conditions in the newborn. We consider three types of abnormal conditions: meconium aspiration syndrome, assisted breathing on a ventilator for more than thirty minutes, and fetal distress. Meconium aspiration syndrome refers to inhalation of meconium by the fetus or the newborn affecting their lower respiratory system.[4] Fetal distress is a condition where the fetus shows indications of a deficiency in the amount of oxygen reaching fetal tissues (NCHS, 1992). These abnormal conditions are considered to be highly associated with maternal stress and were the focus in studies by Currie and Rossin-Slater (2012) and Zahran et al. (2010) that investigate the effects of hurricanes on maternal stress.

[4]Meconium consists of fetus "undigested debris from swallowed amniotic fluid, various products of secretion, excretion and shedding by the gastrointestinal tract." (NCHS, 1992)

Our outcome variables reflect the number of births with a given abnormal condition, per thousand births occurring in a given county in a given month. The mean values for the number of births (per thousand) with each abnormal condition, listed in the second horizontal panel of Table 11, reveal that the most common abnormal condition is fetal distress, which affects on average about 4.5% of all births in a county-month. On the other hand, only 1% of newborns need assisted breathing on a ventilator for more than thirty minutes and meconium aspiration syndrome affects less than 0.3% of births. Given that these abnormal conditions are fairly rare, we also consider the number of births with any of the three abnormal conditions (per thousand births) as an additional aggregated outcome variable. In the individual-level data, the indicator for any one of the three abnormal conditions is equal to one if the newborn is recorded as having at least one of the three abnormal conditions, and equal to zero if it is known that he/she suffered from none of these three conditions. This indicator is then aggregated to the level of county-months to reflect the number of births (per thousand) with any of these three abnormal conditions.

Vertical Panel A of Table 13 shows the effects of heat waves on the fraction of births in a county involving three specific abnormal conditions in the newborn: fetal distress, assisted breathing on a ventilator for more than thirty minutes, and meconium aspiration syndrome. Heat waves during the last trimester of the pregnancy are associated with an increase in fraction of births with fetal distress, by about 2.2 per thousand births. There appears to be no statistically significant relationship between exposure to heat waves and the fraction of newborns who must be placed on a ventilator for more than thirty minutes. However, the results indicate that a heat wave during the second trimester of pregnancy is associated with a statistically significant increase in the fraction of births with meconium aspiration syndrome.

TABLE 13. Newborn abnormal conditions: Effect of heat waves on the number of births (per thousand) with abnormal conditions (key coefficients only)

	Panel A			Panel B
	Meconium aspiration synd.	On a ventilator > 30 min.	Fetal distress	Any of the three conditions
$\beta_{postbirth\_qtr}$	0.214	0.647	0.814	1.897
	(0.212)	(0.417)	(1.121)	(1.201)
$\beta_{trimester3}$	0.295	0.125	2.228**	2.815**
	(0.199)	(0.390)	(1.087)	(1.194)
$\beta_{trimester2}$	0.350*	-0.259	0.540	1.684
	(0.196)	(0.387)	(0.990)	(1.189)
$\beta_{trimester1}$	0.080	-0.395	1.277	2.270*
	(0.235)	(0.414)	(0.972)	(1.270)
$\beta_{preconception\_qtr1}$	-0.122	-0.499	0.325	0.885
	(0.208)	(0.397)	(0.946)	(1.222)
Observations	621,917	621,734	580,342	592,926
Number of counties	3,077	3,077	3,076	3,076

Notes: See notes to Table 12.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Meconium released into the amniotic fluid during delivery, and the associated increase in the risk of meconium aspiration syndrome is related to fetal distress (Currie and Rossin-Slater, 2012). Fetal stress, furthermore, can be created by excessive maternal stress and resultant high levels of maternal cortisol (Zahran et al., 2010). One potential mechanism through which heat waves may result in elevated maternal cortisol levels may be dehydration. It has been reported that Ramadan fasting, for example, is associated with increases in maternal cortisol level (Dikensoy et al., 2009). Dehydration due to restricted fluid intake while fasting might be one reason for this effect. Another mechanism for the effects of heat waves may be the psychological impact that extreme temperatures have on humans. It has been reported in numerous empirical studies that there is a close association between high temperatures and increased aggression and violence that cannot be explained by seasonality of routine activities or by the fact that people are outside more during hot days (see Anderson, 2001 for a review of this literature). There is empirical evidence that non-aggravated assault and domestic violence increase during extremely hot days (Butke and Sheridan, 2010; Card and Dahl, 2011). Stress levels for mothers thus may increase indirectly during heat waves if they are subjected to increased aggression and violence at home or in their communities.

Vertical Panel B of Table 13 shows the effects of heat waves on the fractions of births with at least one of the three abnormal conditions itemized above. Exposure to heat waves during the first and the third trimesters of pregnancy now appears to be associated with an increase in fraction of births with at least one of these abnormal conditions. The magnitude of the coefficient for third-trimester heat waves implies that if there is a heat wave in a county at the period that corresponds to the third trimester of the pregnancies, there are about three additional babies born per thousand births with at least one of the three abnormal conditions. As shown in Table 11, the average number of newborns with at least one of the three conditions in a given county-month is about 81 in each 1000 births. This implies that exposure to a heat wave during the third trimester is associated with about a 3.5% increase in the fraction of births with at least one of these three types of abnormal conditions. These results are comparable in sign and timing to the rates estimated by Currie and Rossin-Slater (2012) and Zahran et al. (2010), who find that hurricane exposure during the first and the third trimesters results in increases in the risk of experiencing either meconium aspiration syndrome or assisted ventilation for more than thirty minutes, and exposure to a hurricane during the second and the third trimesters results in an increase in the risk of fetal distress. The effects of heat waves on maternal-stress-related abnormal conditions in newborns appear to be similar to those of hurricanes in sign and somewhat similar in timing, although the size of the effect is smaller.

Effects of Heat Waves on Maternal Health Conditions

In addition to causing maternal stress that affects the fetus, heat waves might have an adverse impact on pregnant women themselves through an increased risk of various health conditions. These health conditions might be directly related to the physiological impacts of extreme temperatures, or they might be triggered by complications related to heat stress. Accordingly, we investigate the impact of heat waves on health conditions of new mothers. In the data, there are four conditions that are specific to the pregnancy period: pregnancy-associated hypertension, eclampsia, incompetent cervix, and uterine bleeding during pregnancy.[5] We aggregate the indicators for each condition to the county level, so that the outcome variables are the number of mothers per thousand with the given condition. The mean values given in the third horizontal panel of Table 11 indicate that pregnancy-associated hypertension is the most common health condition of the four, affecting on average about 4.3% of mothers giving birth in a given county-

[5]These health conditions are defined as follows in the data documentation (NCHS, 1992): Pregnancy-associated hypertension is diagnosed when there is an increase in blood pressure of at least 30mm Hg systolic and 15mm Hg diastolic on two measurements taken 6 hours apart after 20th week of gestation. Eclampsia refers to the "occurrence of convulsions and/or coma unrelated to other cerebral conditions in women with signs and symptoms of pre- eclampsia". Incompetent cervix is defined as painless dilation of the cervix in the second or the third trimester characterized by a "prolapse of membranes through the cervix and ballooning of the membranes into the vagina, followed by rupture of membranes and subsequent expulsion of the fetus." Uterine bleeding is any clinically significant bleeding during the pregnancy taking into consideration the stage of pregnancy.

month. Each of the other three conditions, in contrast, affects less than 1% of mothers.

Using the specification given in equation 3.2, we likewise estimate the effects of heat waves during each three-month period going back to one year before the birth. Estimation results are presented in Table 14. The results in Panel A indicate that exposure to at least one heat wave during the last two trimesters of a pregnancy is associated with an increase in the fraction of mothers with pregnancy- associated hypertension and eclampsia, whereas heat waves during the first trimester seem to be more closely related to an increase in the fraction of mothers suffering from uterine bleeding during pregnancy.

TABLE 14. Maternal health conditions: Effect of heat waves on the number of mothers (per thousand) who have experienced pregnancy-related health conditions (key coefficients only)

	Panel A				Panel B
	Pregnancy -associated hypertension	Eclampsia	Incompetent cervix	Uterine bleeding	Any of the four conditions
$\beta_{postbirth\_qtr}$	-0.290	0.120	0.098	0.047	1.950
	(0.651)	(0.180)	(0.159)	(0.286)	(1.354)
$\beta_{trimester3}$	1.473**	0.303*	0.0869	0.169	2.436*
	(0.615)	(0.171)	(0.167)	(0.261)	(1.370)
$\beta_{trimester2}$	1.043*	0.417**	0.0817	0.374	3.772***
	(0.625)	(0.212)	(0.222)	(0.382)	(1.322)
$\beta_{trimester1}$	0.654	0.272	-0.0320	0.831**	3.492***
	(0.682)	(0.222)	(0.159)	(0.362)	(1.339)
$\beta_{preconception\_qtr1}$	0.230	0.346*	-0.114	-0.103	1.478
	(0.612)	(0.204)	(0.162)	(0.296)	(1.353)
Observations	722,142	722,142	622,002	580,524	621,889
Number of counties	3,077	3,077	3,077	3,076	3,076

Notes: See notes to Table 12.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The results on eclampsia are consistent with the findings in epidemiology literature which, as noted earlier, suggest that the prevalence of eclampsia is the highest among women who have been in the second trimester of pregnancy during summer months. Further research is needed to understand the biological mechanisms behind the association between extreme heat and hypertension and eclampsia during pregnancy. Uterine bleeding during the early stages of pregnancy appears to be a marker for placental dysfunction [Hasan et al., 2010], but an understanding of the mechanism through which heat waves may result in an increased risk of uterine bleeding will also require further research.

We also consider the effects of heat waves on the number of mothers (per thousand) experiencing any of these four specific adverse health conditions. Similar to the "any of the three abnormal conditions" variable for newborns discussed in the previous section, the indicator for "any one of the four health conditions" is equal to one if the mother is recorded as having at least one of the four health conditions, and equal to zero if it is known that she suffered from none of these four conditions. This indicator is aggregated to the county-level to reflect the number of mothers with at least one of these four health conditions per thousand mothers giving birth in a given county-month.

Vertical Panel B of Table 14 indicates that exposure to a heat wave at any time during the pregnancy is associated with an increased risk of at least one of these health conditions for the mother. For example, the coefficient for 4 to 6 months before birth ($\beta_{trimester\_2}$) implies that a heat wave during the period corresponding to the second trimester of pregnancies in a given county-month is associated with about four more mothers (per thousand) suffering from at least one of the four specified health conditions. When compared to the average number of expectant mothers who have at least one of the four health conditions (given in the third horizontal panel of Table 11), this corresponds to an approximate 3% increase in the fraction of mothers experiencing a pregnancy-related adverse health condition.

Directions for Future Research

The use of air conditioning is an important adaptation to more-frequent heat waves. Unfortunately, earlier Census questions about the presence of air conditioners in the household were not included in the 1990, 2000 and 2010 decennial censuses, and to our knowledge there are no other sources for data on availability of air conditioners at a spatial resolution that would be suitable to incorporate in this study. Not controlling for the level of adaptation in our analysis is not a particular concern in terms of omitted variables bias because the estimating specification (given in equation 3.2) accounts for differential adaptation efforts across states over time and base line differences in pregnancy outcomes across counties through the use of state-by-year fixed effects and county fixed effects, respectively. However, it would be interesting to incorporate into the analysis other potential measures of adaptation and exposure to heat, such as exogenous changes in the cost of air conditioners (due to, for instance, the availability of cheaper air conditioners via new sitings of Walmart stores or other big box retailers of consumer durables.) These controls might help us to understand if the effects of heat waves on health are mitigated by these factors. This is left for future research.

Moreover, there are a number of studies in the sociology literature that indicate that socially produced conditions of vulnerability may need to be considered if we are to understand fully the effects of heat waves on human health (e.g. Klinenberg, 2003; Duneier, 2006; Browning et al., 2006). According to these studies, the magnitude of the impact that heat events may have on health depends heavily on the physical and social characteristics of the neighborhoods, living arrangements and opportunities available for social networking. This suggests that community characteristics may play a role in determining how heat wave exposure and birth outcomes are linked, above and beyond the compositional effects on age, race, and gender.

The social processes underlying these neighborhood characteristics are arguably hard to measure and quantify. To our knowledge, there are no data sources that provide standard measures of these community characteristics nationally and at a high level of spatial aggregation. As discussed in the context of adaptation, not controlling for such characteristics is a concern for our estimates of the effects of heat waves on birth outcomes to the extent that these characteristics vary systematically over time with the heat waves across counties within each state (i.e. variation that is not captured by state-by-year fixed effects and county fixed effects), and not accounted for by socio-demographic controls. However, if such data exist, they could be used to explore the interactions between these characteristics and heat waves in terms of their impact on health at birth.

One particularly interesting finding in Browning et al. (2006) is that the mortality rate across neighborhoods during the 1995 Chicago heat wave can be explained by commercial conditions in these neighborhoods measured in terms of commercial density and "commercial decline" which takes into account the condition of the commercial buildings and the nature of the business activity taking place. They find commercial density and low commercial decline in a neighborhood is negatively associated with heat mortality. This suggests that healthy commercial conditions effectively protect urban communities from the mortality impact of the heat wave. The authors explain that commercial enterprises generate social networking opportunities and facilitate access to information about neighborhood functioning, especially for elder populations.

Another explanation for the important role that the commercial conditions in a community play on heat wave vulnerability is that commercial buildings may function as informal cooling spaces. They may reduce heat exposure especially for individuals who do not have access to an air conditioner in their own living spaces. The number of commercial buildings can also be used as a proxy for availability of informal cooling opportunities in future work that explores how the effects of heat wave vary by availability of air conditioning and whether exposure to extreme heat can be mitigated through making air conditioning more accessible.

Conclusion

Motivated by concerns about the potential health impacts of climate change, and curiosity about the importance of alternative emphases for adaptation policies, we have examined whether heat waves have any statistically discernible impact on fertility decisions and a variety of birth outcomes for both the newborn and the mother. Using Natality files on birth outcomes and SHELDUS data on heat waves, we find no statistically significant impact of heat waves on birth rates and no statistically significant changes in the racial and educational composition of the set of mothers as a consequence of exposure to heat waves. These results imply that heat waves do not lead to identifiable changes in fertility decisions or systematic selection into fertility by different socio-economic groups.

We investigate whether heat waves during our updated time interval (1989-2008) continue to have the adverse effects found for earlier periods on the most commonly used birth outcome measures (i.e. birth weight and gestational age). However, we also consider the effects of heat waves on the incidence of abnormal conditions in the newborn that can be related to maternal stress, as well as problems with the mothers health during pregnancy. We determine that exposure to heat waves in the second trimester of pregnancy has a negative and statistically significant impact on gestational age, but the effects of heat waves on the most widely used birth outcomes are rather subtle.

However, our findings do support that the heat waves do seem to have some association with increased maternal stress and adverse health outcomes for both the newborn and the mother. Specifically, we find evidence that babies born in the areas that have suffered heat waves while the baby was in utero are more likely to suffer from at least one of a set of abnormal condition at birth (where this set includes fetal distress, assisted breathing for more than thirty minutes, and meconium aspiration syndrome). We also find that heat waves during pregnancy are associated with an increase in the risk of at least one of a set of adverse health conditions for the mothers themselves (where this set includes pregnancy-associated hypertension, eclampsia, incompetent cervix, and uterine bleeding).

If heat waves were to result in a greater opting-out of fertility by those groups of mothers who are in better health or who have babies with better birth outcomes, then the negative association between heat waves and shorter gestation might be merely a reflection of this non-random selection. Our finding of no statistically significant change in the racial and educational composition of the set of mothers lets us conclude that the selection into fertility is probably not driving our findings concerning the association between heat waves, gestational age, adverse health conditions of the mother, or abnormal conditions for the newborn.

The contributions of this study are three-fold: First, we emphasize the importance of questioning whether there is systematic selection into (or out of) fertility in response to heat waves. Any analysis of the average effects of such events on groups must first consider the stability of the characteristics of those groups.

Second, the economic literature on the link between ambient temperature and birth outcomes has previously focused on the standard measures of health at birth, specifically birth weight and gestational age. Our findings indicate that, although the effects on these commonly used measures are modest, in- utero exposure to extreme heat results in other maternal stress-related health complications in newborns. Further research is of course needed to quantify the link between childrens experiences with these health conditions as newborns and their future health, education and labor market outcomes.

Third, the findings in this paper also suggest that exposures to heat waves during pregnancy pose a risk for the mothers health as well. Expectant mothers who experience a heat wave while pregnant are more likely to suffer from serious, even life-threatening, health conditions. Measurement of the social costs associated with these health conditions, and the value of avoiding them, is also left for future research. Given the link between a mothers health conditions during pregnancy and her future health and birth outcomes, the effects of heat waves on expectant mothers health should perhaps be recognized as a potentially important component of the adverse health effects of extreme temperatures associated with climate change.

To make recommendations for climate change adaptation policies, it will be important to know more about the mechanisms whereby extreme heat events affect both neonatal and maternal outcomes. Even without a precise knowledge of these underlying mechanisms, however, we can conclude that the adverse impacts of heat waves on birth outcomes and mothers health must be acknowledged as contributing to the health costs associated with extreme weather events. Given that heat waves appear to have become more frequent, more severe, and more geographically widespread as a result of climate change, the need for this knowledge may be increasing.

CHAPTER IV

EFFECTS OF UNCONVENTIONAL OIL AND NATURAL GAS DEVELOPMENT ON FERTILITY AND BIRTH OUTCOMES

I was the primary contributor to the empirical work presented in this chapter, and did all the writing. The analysis benefited from contributions of Ralph Mastromonaco in data cleaning and developing empirical models.

Introduction

Recent technological advances in hydraulic fracturing and horizontal drilling have provided access to low-permeability oil and gas reservoirs, such as shale formations, coal seams, and tight sand formations. This has resulted in a rapid expansion of unconventional oil and natural gas development (UONGD) of numerous reservoirs that were previously uneconomical to exploit. Currently, up to 95 percent of all new oil and natural gas wells drilled in the U.S. involve hydraulically fracturing (or "fracking"), and these wells account for more than 43 percent of total U.S. oil production and 67 percent of natural gas production (DOE, 2013).

The expansion of UONGD has important economic, environmental and health implications. The national economic benefits associated with potential energy independence have been one of the most important motivating factors for promotion of UONGD. According to the latest world report of the U.S. Energy Information Administration (EIA), the U.S. ranks second in the world in technically recoverable shale gas resources, and fourth in shale oil resources (EIA, 2013). Therefore, the shift to domestic energy supplies with UONGD may potentially reduce U.S. reliance on foreign oil and support U.S. energy independence. Moreover, UONGD activities can have a significant impact on local economies. There are studies indicating that UONGD creates jobs and leads to increases in incomes for local populations (Maniloff and Mastromonaco, 2014; Weber, 2012).

Shale gas has also been promoted as a clean source of energy. Natural gas is known to emit fewer pollutants and greenhouse gases compared to other fossil-fuel energy sources such as coal. The recent fall in U.S. carbon dioxide emissions is thought to be a result, in part, of the switch from coal to natural gas due to the increased supply of shale gas and the associated fall in the price of natural gas (Holladay and LaRiviere, 2013; Murray et al., 2014). In contrast to the potential positive environmental impact that shale gas may have at the macro scale, the unconventional drilling activity and extraction process has raised public health concerns for some of the local communities where UONGD takes place. Leakage of chemicals, air pollution and water contamination, as well as negative externalities related to increased truck traffic and noise pollution are often mentioned as the mechanisms through which UONGD may have an adverse impact on human health. A discussion on these mechanisms and the link between UONGD and health is presented in the next section.

Considering that current projections indicate that the shale "boom" will last for at least several more decades (EIA, 2015), it is critical to understand the types of adverse impacts that UONGD might have on human health and address them accordingly. However, there are only a few existing studies examining the direct relationship between unconventional drilling activity and human health (discussed in the next section). In this paper, we aim to fill part of this gap in the literature by investigating the link between UONGD and infant health, and we innovate by analyzing a larger geography than has been considered in previous literature. We use a yearly panel of all counties in five states (Arkansas, Colorado, North Dakota, Pennsylvania, and Texas). These states are among the top in experiencing a boom in unconventional oil and natural gas drilling activity. We find that there is a negative association between the number of unconventional wells drilled and birth weights in a given county after controlling for mother's characteristics, economic conditions within the county, time-invariant county characteristics and year fixed effects. This association, while statistically significant, appears to be very small in magnitude. One reason for small estimated average impacts may be the systematic changes in the composition of mothers giving birth in counties where there has been UONGD activity. The data indicate that the fraction of births to mothers with college education increases with the intensity of unconventional drilling activity, which would tend to result in improvements in observed birth outcomes. No statistically significant effects on gestational age or the prevalence of low birth weight or pre-term births are detected. These findings are robust to a range of specifications.

When the number of unconventional wells drilled in a given county-year is interacted with an indicator for urban and rural counties, to allow for differential impacts, the results indicate that the estimated negative effect of unconventional drilling on birth weight is larger in rural areas. The more pronounced association between UONGD and adverse birth outcomes in rural counties perhaps suggests that the negative health impact of UONGD may be mediated primarily through water contamination. The potential physical mechanisms require further investigation.

The rest of this paper proceeds as follows. Section 2 provides background information about unconventional drilling and potential mechanisms for an impact on health, and outlines the relevant existing literature. Section 3 describes the data. Section 4 presents the empirical models used and discusses the results. Section 5 concludes.

Background

Unconventional Drilling Process and Mechanisms for Health Impact

The U.S. government adopted a series of policies to encourage the development of unconventional oil and natural gas resources in response to the severe energy crisis in the late 1970s (Krupnick, 2013). Since then, there have been significant technological advancements in two techniques used in the extraction of unconventional resources, hydraulic fracturing and horizontal drilling, which made UONGD economically viable.

Unconventional oil and gas resources include shale gas or oil, tight gas, and coal-bed methane trapped in shale formations, sandstone or limestone, or coal seams. Unlike conventional reservoirs which allow gas to flow easily towards a well, unconventional reservoirs have low capacity to transmit a fluid and must be mechanically stimulated to create additional permeability and to free the gas for collection (DOE, 2013). One of the most widely used stimulation methods is hydraulic fracturing of the reservoir. Hydraulic fracturing, or fracking, involves injection of a large volume of water (typically at least three millions of gallons), mixed with sand and chemicals, into rock formations thousands of feet below the surface. If “horizontal drilling” is employed, the well is drilled down to a level just above the target depth where the shale gas formation exists, and then the path deviates and becomes horizontal. The goal is to orient each horizontal well in a direction that maximizes the number of natural fractures intersected in the shale to provide additional pathways for the gas that is locked away in the shale (DOE, 2013).

Water Contamination

The risk of groundwater and surface water contamination associated with unconventional drilling is the leading source of concern for public health. During the process of hydraulic fracturing, at least 20 to 25 percent of the water injected comes out of the well as "flowback water," and additional volumes of waste water are produced over the life of the well (NETL, 2013). In some shale "plays", most of the flowback water and waste water produced are cleaned up and re-used in the fracturing of other wells. When not re-used, the water is consigned to deep disposal wells.

The drill pipe that transmits the drilling fluids is separated from groundwater aquifers by roughly nine inches of cement and two inches of solid steel. The cement and the steel casing are thicker (up to sixteen to twenty inches in diameter in total) in the shallower parts of the well to protect near-surface groundwater (NETL, 2013). Water contamination may result from leakage of hydraulic fracturing fluid or flowback water through or around the well bore casing to shallow groundwater, or through accidental spillings of these fluids into surface water (NETL, 2013). These leakages and spills may occur if there are faulty well casings, improper well installations, drilling pad or pipeline incidents, or tank truck accidents.

The major concern about these potential leakages and spills stems from the chemicals used in the fracking fluid. Underground injection of any fluids during hydraulic fracturing operations are excluded from the U.S. Environmental Protection Agency's (EPA) regulatory authority under the Safe Drinking Water Act (NETL, 2013). No regulation requires disclosure of chemical constituents of fracking fluid. However, it has been reported that some of the chemicals used, including methanol and BTEX compounds (benzene, toluene, ethylbenzene and xylene) are either known or possible human carcinogens, or chemicals that are regulated under the Safe Drinking Water Act because of their risks to human health (Hill, 2013). According to NETL (2013), the EPA is attempting to exercise authority under the Toxic Substances Control Act to require disclosure of chemical constituents of fracking fluid.

Colborn et al. (2011) identify a list of chemicals that have been used during natural gas operations and the potential health impacts associated with these chemicals. They point out that more than 75% of the chemicals they identified could affect the skin, eyes, and other sensory organs, and the respiratory and gastrointestinal systems. They also argue that, besides these relatively short-term effects, many of these chemicals have potential long-term health effects that are not immediately observed. In particular, approximately 40-50% of these chemicals could affect the brain/nervous system, immune and cardiovascular systems, and the kidneys; 37% could affect the endocrine system; and 25% could cause cancer and genetic mutations.

There are studies documenting evidence of both surface water and groundwater contamination associated with increased UONGD. Olmstead et al. (2013) examine the extent to which shale gas development activities affect surface water quality, focusing on the Marcellus Shale area in Pennsylvania. They find that increases in the upstream release of treated shale gas waste and increases in the spatial density of well pads are associated with increases in downstream concentrations chloride and total suspended solids. In a case study conducted in the Pavillion gas field of Wyoming (EPA, 2011), high concentrations of benzene, xylenes, gasoline range organics, and diesel range organics were detected in ground water samples near pits that are used for disposal of drilling cuttings, flowback, and produced water. The authors of the report conclude that these pits are a source of shallow ground water contamination in the area of investigation. In another study, Osborn et al. (2011) document evidence for methane contamination of drinking water associated with shale-gas extraction in aquifers overlying the Marcellus and Utica shale formations of northeastern Pennsylvania and upstate New York.

Any contamination in public water systems would potentially be reported and addressed under the requirements of Safe Drinking Water Act. However, the testing and monitoring of water quality in private wells is the responsibility well owners. Considering that there are many private wells in rural areas that rely on shallow groundwater for household and agricultural use (up to one million wells in Pennsylvania alone, according to Osborn et al., 2011), and that these wells are not subject to regular monitoring for compliance with EPA's drinking water standards, it is safe to assume that rural populations are at a greater risk of exposure to water contamination associated with UONGD.

Air Pollution

All stages of oil and natural gas development are known to produce a variety of air emissions such as toxic volatile organic compounds (VOCs), other hydrocarbons including BTEX, methane, particulate matter, polycyclic aromatic hydrocarbons, sulfur oxides and nitrogen oxides (EPA, 2008; EPA, 2011). Wells, production tanks, compressors and pipelines, and maintenance operations all contribute to total pollutant emissions (Witter et al., 2013). Additionally, the process of hydraulic fracking requires heavy truck traffic as well as use of other industrial diesel equipment. Trucks bring in the materials needed for the drilling process. More importantly, the water used in drilling is typically delivered by a convoy of tanker trucks and produced water is hauled away for treatment or disposal, also by trucks (NETL, 2013). Emissions from combustion associated with trucks, generators used to power drilling rigs, hydraulic fracturing, and flaring include particulate matter (PM), VOCs, sulfur oxides (SOx), and nitrogen oxides (NOx) (Witter et al., 2013). These pollutants are associated with increased risk of a wide variety of acute and chronic health conditions. (See McKenzie et al., 2012 for the list of health conditions associated with each of these pollutants.)

Emission inventories in Garfield County, Colorado (CDPHE, 2009), indicate that overall VOCs and benzene emissions increased 40% and 38%, respectively, from 1996 to 2007, and that these trends are thought to be a result of the increase in oil and gas development activity in the county. Litovitz et al. (2013) estimate the relation between shale gas extraction activities in Pennsylvania and regional air pollution. They find that the shale gas extraction is linked to increases in VOCs, NOx, and PM2.5 emissions. However, when they separately estimate the magnitude and type of emissions associated with potential sources of emissions in different stages of shale gas development (such as well construction, transport trucks, shale gas production, and compressor stations), they conclude that most emissions are related to ongoing activities (i.e. gas production and compression) rather than actual development and thus are largely unrelated to the unconventional nature of the resource.

UONGD and Human Health

Although there are concerns surrounding the pollution impacts that unconventional drilling may have on water and air, there is a clear gap in the literature that reports population-based empirical evidence on health impacts. In one study, McKenzie et al. (2012) identify the pollutants associated with drilling, and then, based on these estimated pollution levels and expected exposure to these pollutants, they estimate the likely health implications of drilling. Their findings suggest that residents living within a few miles of a well have an increased risk of suffering from a wide variety of acute and chronic conditions. The authors indicate that health effects resulting from air emissions during development of unconventional natural gas resources are most likely to occur for residents living nearest to the well pads.

There are a few other studies (such as Bamberger and Oswald, 2012; Perry, 2013; Steinzor et al., 2013) based on interviews and local community surveys. These studies address the potential adverse impact that unconventional drilling may have on the health of local populations. They all suggest that there may be a link between UONGD and adverse health, and call for further research. In their recent review of this literature, Werner et al. (2015) conclude that although the current literature generally lacks methodological rigor, there is no evidence to rule out such health impacts. There is a clear need for further empirical investigation and the present study aims to help fill part of this gap in the literature.

UONGD and Birth Outcomes

In this study, we focus on the association between UONGD and birth outcomes. Health at birth is considered an important predictor of health in adulthood and other socioeconomic outcomes later in life (see Currie, 2009; Almond and Currie, 2011a; Almond and Currie, 2011b). Moreover, studying the impact of an environmental factor on health at birth has empirical advantages over studying adult health. When one tries to investigate factors that affect health outcomes for adults, it is hard to isolate the effect of a particular factor from the cumulative effects of the individual's lifetime exposure to a vast array of environmental factors, potentially across several different geographical areas. It is also possible, when we observe an increase in the number of deaths that occur during or after an environmental shock, that this might be merely a minor displacement in the timing of imminent mortality. That is, an environmental shock might trigger health complications for individuals who are already suffering from serious health problems and who would likely have died in a few days or weeks anyway. Birth outcomes are less likely to be subject to this type of temporal displacement effect because of the limited time-period of prenatal exposure.

There is a long list of studies that find an association between exposures to pollutants that are thought to be linked to drilling activities (including VOCs, benzene, PM, SO_2 and NO_2) and infant health outcomes (e.g. Dejmek et al., 2000; Currie and Schmieder, 2009; Slama et al., 2009; Currie and Walker, 2011; Zahran et al., 2012; Dadvand et al., 2013; Lavaine and Neidell, 2013. Also see Stillerman et al., 2008 for a review of the epidemiology literature.) The findings in these studies, in general, suggest that there is a relation between exposure to these pollutants and inferior birth outcomes, in particular lower birth weight. It is worth noting that a subset of these studies (including Currie and Walker, 2011; Zahran et al., 2012; Lavaine and Neidell, 2013) utilize quasi-experimental research designs, which suggest that the negative relationship between these pollutants and low birth weights may indeed be causal.

The existing literature seems to suggest that a mix of genetic, socioeconomic and environmental factors plays an important role in determining health at birth. Almond and Currie (2011a) categorize into three groups the adverse environmental conditions that cause disruptions to prenatal development: (1) factors affecting maternal and thereby fetal health (e.g. nutrition and infection), (2) economic shocks, and (3) pollution. There is substantial evidence in the literature that links each of these factors to birth outcomes (including prenatal care, nutrition, maternal smoking, diseases such as influenza and malaria, parental income, education, and exposure to pollution and toxic releases. See Almond and Currie, 2011a) UONGD may have an association with factors related to all three categories mentioned above. However, to our knowledge, there have been only two attempts in the literature to directly link UONGD to birth outcomes.

The most recent study, by McKenzie et al. (2014), examines births in rural Colorado between 1996 and 2009 and investigates the associations between birth outcomes and maternal residential proximity to unconventional natural gas development. They find that the prevalence of congenital heart defects and neural tube defects increases with exposure. They also find a small association between exposure and pre-term birth.

In the other study, Hill (2013) focuses on shale gas development in Pennsylvania for the period 2003-2010. She uses a difference-in-differences research design where mothers who live in proximity to future wells, as designated by well permits, are used as the a comparison group. She finds that the introduction of drilling increases low birth weight among births to mothers who live within 2.5 km of an active well compared to births to mothers who live within 2.5 km of a future well. She also finds adverse effects using measures such as small-for-gestational-age and APGAR scores, while she does not find any effects on gestation periods or premature births.

The findings in both of those earlier studies suggest that shale gas development may pose significant risks to infant health. The present work confirms that there is indeed a link between exposure to unconventional drilling activities and inferior health at birth. It expands the geography studied to cover states that overlie some of the largest shale plays in the U.S.

Data

Drilling Data

The data on UONGD are available from DrillingInfo, a private-sector data provider. The data include very detailed information on all oil and gas wells (conventional and unconventional) in the U.S., including their location, production over time and the geological reservoir they exploit. We use the year in which a well first reported production as a proxy for the year that it was drilled. This may result in under-identification of the total number of wells drilled because it does not include experimental wells. To match the geographic resolution in the data that we have on birth outcomes, we aggregate the data on wells up to the county level to measure the total number of wells drilled in a given county-year.[1]

[1] The data on production over time is available at the lease level which in some cases include more than one well (when there are multiple wells drilled under the same lease). Therefore, we do not have the information on production over time for each well, if the lease includes multiple wells. However, we do know how many wells there are associated with each lease in the data, and assume that all wells on the same lease started production at the same time.

We identify a well as an unconventional well if it is drilled into a known shale reservoir or if it is explicitly specified as “unconventional” or “shale” in the reservoir section of the data.[2] We focus on five states, Arkansas, Colorado, North Dakota, Pennsylvania, and Texas, which cover most of the largest shale plays in the U.S. The major shale plays include Marcellus (Pennsylvania), Barnett (Texas), part of Haynesville (Texas), Eagle Ford (Texas), Bakken (North Dakota), Fayetteville (Arkansas), and Niobrara (Colorado).

As outlined above, the unconventional drilling process is arguably the bigger concern for health, as opposed to the actual production process. Therefore, we focus on the number of unconventional wells drilled as our key explanatory variable. Figure 7 shows the total annual number of unconventional wells drilled over time across these five states. A substantial expansion in the unconventional drilling activity can be observed starting 2004-2005.

Birth Data

The data on birth outcomes are from the National Vital Statistics System for the period 2000-2010. The restricted-use version of the data identifies the location of residence for each mother at the county level. In addition to information on each newborn’s health at birth, the data provides information on the mother, including

[2]We assume the wells for which the reservoir information is missing in the data are conventional wells. This is a reasonable assumption considering the fact that the number of wells with missing reservoir information in the data did not change over time within the time period that we study (with the exception of the wells in Pennsylvania). This implies that most of the wells with missing reservoir information were drilled prior to 2000 and are likely to be conventional wells. We do sensitivity analysis where we assume wells without reservoir information are unconventional wells if they are drilled in a shale county, and a conventional wells if they are drilled in a non-shale county where a county if defined as shale if it has at least one unconventional well drilled. We also consider a sample which excludes wells without the reservoir information.

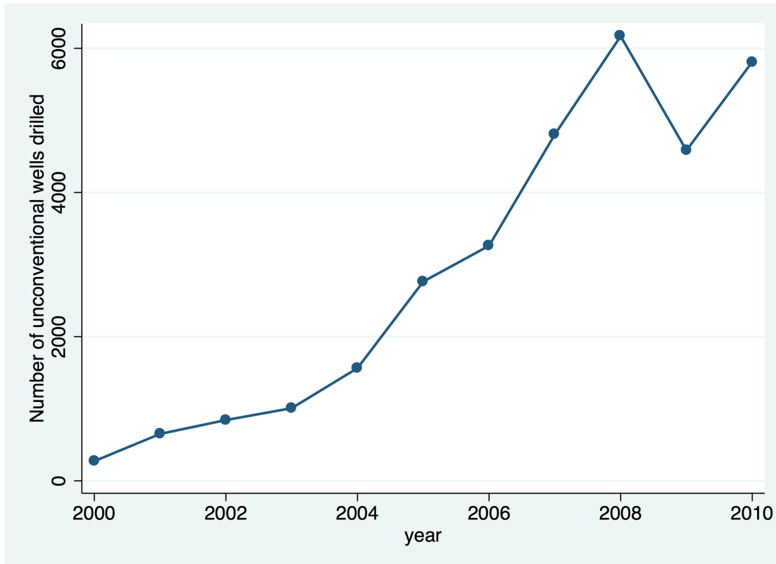

FIGURE 7. Number of unconventional wells drilled over time

age, race, marital status and education. We aggregate the data on singleton births to the county level so that the unit of observation becomes a county-year.

Other Data

To consider the potential link between the UONGD and fertility, we use the birth rate in each county as the outcome variable. Birth rate is calculated by dividing the total number of births in a given county-year by the number of women aged 15-44 living in that county (in thousands). The population data are from Surveillance Epidemiology and End Results (SEER), which provides annual population estimates (by gender and age) for each county.

County-level employment and wages are used as controls in all specifications. These data are from the Quarterly Census of Employment and Wages (QCEW) compiled by the Bureau of Labor Statistics.

Empirical Model and Results

Effects on Fertility and Composition of Mothers

In the data, we can observe health at birth only for babies born to mothers who choose to become pregnant. If UONGD results in changes in fertility, or changes in the composition of mothers giving birth, then the observed changes in health at birth may not reflect the true effect of UONGD on birth outcomes we consider. Therefore, we begin by investigating the potential impact that UONGD may have on fertility and the characteristics of the mothers who are giving birth.

For the effects on overall fertility, we consider how birth rate (the number of births per thousand women of child-bearing age in a given county-year) varies systematically with the number of unconventional wells drilled in the same county in the past year. The most flexible regression equation used is:

$$y_{ct} = \beta Wells_{c(t-1)} + X_{c(t-1)} \cdot \theta + \alpha_t + \alpha_c + \epsilon_{ct} \tag{4.1}$$

where y_{ct} is the birth rate in county c in year t. As reviewed earlier, there are studies indicating that UONGD has a positive impact on local economic conditions and improved economic conditions are known to be correlated with both fertility decisions and birth outcomes.[3] Therefore, we add lagged measures of employment and average weekly wages to control for economic conditions in each county-year. Moreover, we account for the potential impact of conventional drilling activity on fertility and birth outcomes by adding the number of conventional wells drilled in the past year as a control variable. Therefore, the estimated impacts implied by our

[3]As examples of this literature, see Dehejia and Lleras-Muney, 2004; Lindo, 2011; Schaller, 2015.

coefficient estimates are relative to having no wells drilled in the county. $X_{c(t-1)}$ denotes these county-level controls for lagged economic indicators and lagged conventional drilling activity.

We also account for time-invariant county characteristics that are potentially correlated with both fertility decisions and the UONGD by including county fixed effects denoted by α_c in the above equation. Finally, we include year fixed effects, α_t, to account for any changes in fertility over the years that are common to all counties.

The first column in Table 15 presents the estimated effect on birth rates of the number of unconventional wells drilled in the past year. The point estimate suggests that there is a very small but statistically significant decrease in birth rate associated with unconventional drilling. One explanation for this may be that unconventional drilling and related economic activities may result in a temporary increase in population of women aged 15-44 in counties, but no change, or a smaller increase, in number of births (i.e. an increase in the denominator but no corresponding increase in the numerator). If the new population migrating into a county for drilling activities has a lower fertility rate than the existing population (perhaps due to selection out of fertility because of temporary relocation), this translates into a decrease in birth rate. Indeed, the last two columns in Table 15 indicate that there is an increase in population of females of reproductive age associated with UONGD in a given county-year, but no change in number of births.

Table 16 presents the results of a model where the number of new unconventional wells is interacted with indicators for rural and urban counties where the indicator for urban is equal to one if the county is classified as "in metro area" in the Rural-Urban Continuum Code. The results suggest that there is a

TABLE 15. Effects of number of unconventional wells drilled on fertility, population of females of reproductive age, and total birth count

	Birth rate	Log(Female population)	Number of births
Unconventional wells drilled	-0.00495*	0.00009**	0.13123
	[0.00256]	[0.00004]	[0.11499]
N	5,589	5,589	5,599
R^2	0.113	0.269	0.398
# of counties	509	509	509
Mean	67.32	1.336	1233
SD	15.23	1.699	4303

Notes: All regressions include relevant controls, county fixed effects, and year fixed effects. Birth rate is the total number of births in a county-year per thousand women of child-bearing age in that county. $Log(Female\ Population)$ is the natural log of female population (in thousand) aged between 15 and 44 in given county-year.
Robust standard errors in brackets, clustered at county level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

statistically significant negative association between UONGD and both the birth rate and a statistically significant positive association between UONGD and the female population, but only in urban areas. This implies that there is no change in the female population in rural areas associated with UONGD, and there is no change in overall fertility for the local rural population.

TABLE 16. Differential effects on fertility, population of females of reproductive age, and total birth count in rural and urban counties

	Birth rate	Log(Female population)	Number of births
Rural - Unconventional wells drilled	-0.00265	0.00003	0.00262
	[0.00386]	[0.00004]	[0.02943]
Urban - Unconventional wells drilled	-0.00696***	0.00015***	0.21114
	[0.00123]	[0.00003]	[0.18843]
N	5,589	5,589	5,599
R^2	0.113	0.27	0.399
# of counties	509	509	509
Mean	67.32	1.336	1233
SD	15.23	1.699	4303

Notes: See notes to Table 15

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

To examine compositional changes, we consider how the fraction of births to mothers in different racial and educational groups has changed with the prevalence of fracking, again using the specification given in Equation 4.1. The results presented in Panel A of Table 17 indicate that there is a statistically significant decrease in the fraction of births to mothers with less than a high school education and a statistically significant increase in the fraction of births to mothers with a college education. This finding is consistent with the findings in Hill (2013) which indicate increased college completion rates among mothers giving birth after drilling compared to college completion rates among new mothers observed prior to drilling. If a UONGD boom results in a disproportional change in incomes for more educated people in the rural areas, we may observe increased fertility among more-educated women associated with the intensity of unconventional drilling as income and fertility is known to be positively correlated. It may also be a result of possible changes in opportunity cost of child-bearing for college educated mothers. A disproportional change in incomes for college educated men in the rural areas may also imply a decrease in opportunity cost of child-bearing for more educated women, assuming that college educated women are more likely to have college educated spouses.

TABLE 17. Effects of number of unconventional wells drilled on educational and racial composition of mothers

	Panel A			Panel B		
	Fraction of births to mothers with			Fraction of births to		
	Less than high sch. edu.	High sch. or some coll.	College or more edu.	White mothers	Black mothers	Other non-white m.
Unconventional wells drilled	-0.03067* [0.01729]	-0.00742 [0.00995]	0.03810** [0.01734]	-0.00287 [0.00431]	-0.00156 [0.00291]	0.00443 [0.00336]
N	5,588	5,588	5,588	5,588	5,588	5,588
R^2	0.233	0.046	0.322	0.025	0.011	0.019
# of counties	509	509	509	509	509	509
Mean	210.4	549.1	240.5	905.8	68.33	25.91
SD	108.7	107	143	136.4	117	77.95

Notes: Robust standard errors in parentheses, clustered at the county level. All regressions include relevant controls, county fixed effects, and year fixed effects. Fraction of births are calculated by dividing total number of births to mothers with the given characteristic in a given county-year by total number of births in thousand in that county.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Looking at the estimates presented in Panel B of Table 17, however, we can conclude that there is no association between UONGD in a given county and the racial composition of women giving birth in that county.

Table 18 presents the results of a model where the effects of unconventional drilling activities on educational and racial composition of mothers are allowed to be different between rural and urban areas. The results in Panel A suggest that the changes in educational composition of mothers are observed only in rural counties. More births to college-educated mothers and fewer births to mothers with less than high school education, in the presence of increased fracking activity, is likely to result in improvements in average birth outcomes in rural communities with UONGD, rather than adverse health effects. This is because babies born to more-educated mothers are more likely to have superior birth outcomes, and adverse birth outcomes such as low birth weight and short gestation are more prevalent among mothers who are the least educated.

TABLE 18. Differential effects on educational and racial composition of mothers in rural and urban counties

	Panel A			Panel B		
	Fraction of births to mothers with			Fraction of births to		
	Less than high sch. edu.	High sch. or some coll. edu.	College or more edu.	White mothers	Black mothers	Other non-white mothers
Rural - Unconv. wells drilled	-0.04726**	-0.01833	0.06558***	0.00061	-0.01095	0.01034
	[0.02355]	[0.02491]	[0.01876]	[0.00945]	[0.00803]	[0.00908]
Urban - Unconv. wells drilled	-0.02038	-0.00066	0.02104	-0.00503	0.00427*	0.00076
	[0.02017]	[0.01290]	[0.02765]	[0.00398]	[0.00242]	[0.00335]
N	5,588	5,588	5,588	5,588	5,588	5,588
R^2	0.233	0.046	0.322	0.025	0.011	0.019
# of counties	509	509	509	509	509	509
Mean	210.4	549.1	240.5	905.8	68.33	25.91
SD	108.7	107	143	136.4	117	77.95

Notes: See notes to Table 17

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Effects on Birth Outcomes

For the effects of unconventional drilling on health at birth, we focus on five county-level birth outcomes: (1) average birth weight, (2) average gestational age at birth, (3) average APGAR score, (4) number of births per thousand with low birth weight where low birth weight is defined as birth weight less that 2500 grams, and finally (5) number of pre-term births per thousand where pre-term is defined as having gestational age less than 37 weeks. In Figure 8, how each of these birth outcomes has changed over time are shown against the time trend in unconventional drilling. All of these measures considered, with the exception of pre-term birth, seem to have a time trend that suggests that birth outcomes are getting poorer over time.

The regression equation used is similar to Equation 4.1 given above:

$$Outcome_{ct} = \beta Wells_{c(t-1)} + X_{c(t-1)} \cdot \theta + M_{ct} \cdot \gamma + \alpha_t + \alpha_c + \epsilon_{ct} \tag{4.2}$$

The newly added variable M_{ct} denotes the vector of controls including gender composition of the newborns and the socio-demographic composition of the set of expectant mothers in each county-year. The socio-demographic controls are also measured at the county level and denote the fraction of births in a given county-year to mothers in different racial, age and marital status groups.[4]

[4]Specifically, we control for the fraction of births in a given county-year to (1) white mothers (omitted category), black mothers and other non-white mothers, (2) mothers aged less than 18, 18-22, 23-28 (omitted category), 29-34, and 35-and-over, and (3) non-married (omitted category) and married mothers. Controls for education level of the mother are not included in this reduced form estimation as they are found to be endogenously changing with UONGD. Considering that the change in educational composition of the mothers with UONGD is likely to result in improvements in birth outcomes, the coefficient estimated in this model that excludes education as a control is likely to reflect a lower bound estimate for the effect that UONDG may have on birth outcomes. In fact, estimating the same equation with education controls increases the point

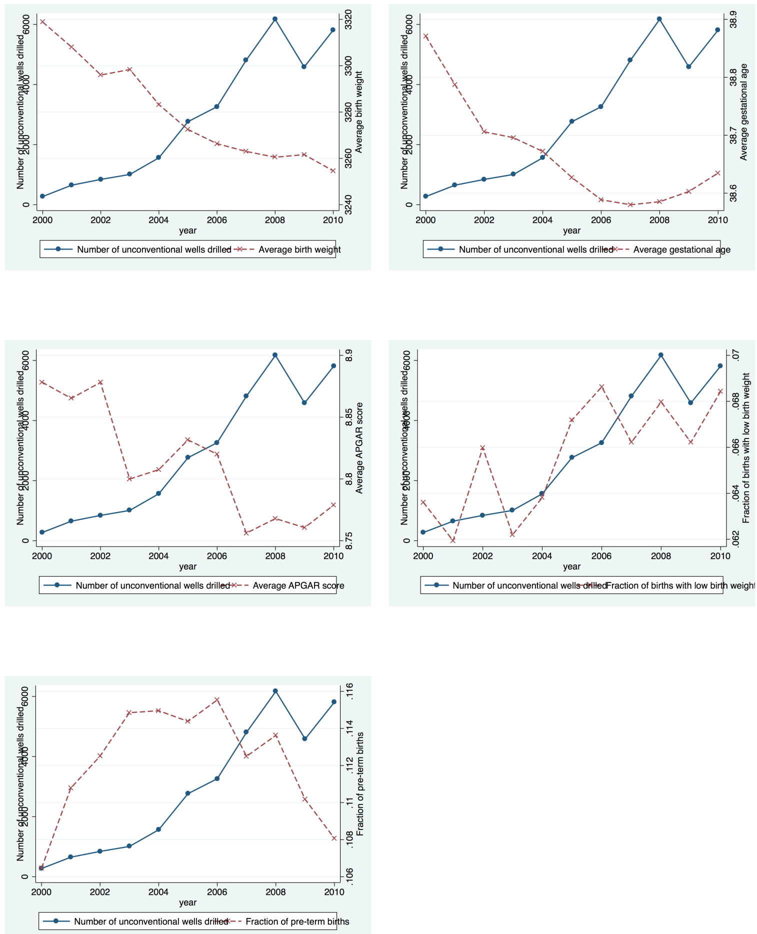

FIGURE 8. Birth outcomes over time

Table 19 shows the estimated effects of unconventional drilling on the above-mentioned birth outcomes. The estimates suggest that the number of unconventional wells drilled in the past year has a statistically significant but very small negative association with birth weight. The magnitude of the coefficient in the birth weight model can be interpreted as about a 0.03 gram decrease in average birth weight per newly-drilled well, which suggests that the link between

estimate for number of wells in absolute value. The results of this estimation is presented in Table 27 in Appendix.

UONGD and birth weight, though statistically significant, is small in magnitude. No statistically significant effect is detected for other birth outcomes.

TABLE 19. Effects of number of unconventional wells drilled on birth outcomes

	Birth weight	Gestational age	APGAR	Low birth weight (<2500g)	Pre-term (<37 weeks)
Unconventional wells drilled	-0.02779** [0.01090]	-0.00003 [0.00007]	0.00031 [0.00030]	0.00293 [0.00269]	0.00271 [0.00728]
N	5,588	5,587	4,952	5,588	5,587
R^2	0.128	0.075	0.022	0.04	0.026
# of counties	509	509	509	509	509
Mean	3280	38.67	8.808	65.7	112.3
SD	110.6	0.408	0.381	36.16	51.61

Notes: All regressions include controls, county fixed effects, and year fixed effects.
Robust standard errors in brackets, clustered at county level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

One reason for the estimated effect being small can be the changes in educational composition of mothers discussed in the previous section. If there is an increase in fraction of college educated mothers and a decrease in the fraction of less-educated mothers associated with unconventional drilling activity, the effect of this change on birth outcomes may offset any negative impact that UONGD may have in the results.

Another reason for the small magnitude of the effect may be the county-level aggregation in the data. County-level analysis implicitly assumes that the exposure is the same for all births occurring within the same county. It is likely that only a small subset of women who live closest to the wells, or those who live in areas where the density of the wells are the highest, are affected by fracking activities and their associated pollution. Even if there is a substantial impact on births to these small group of women, the county average birth outcomes may change only by a very small amount. In fact, the effect implied by the results in Hill (2013), which considers as "affected" only those women living within 2.5 km of a well, is very large compared to the findings in this study. She finds that shale gas development decreases birth weight by 46.6 grams. This corresponds to a 0.9 gram (per well) decrease in the average birth weight for all births in the state, in a back-of-the-envelope calculation that assumes that the wells have zero effect anywhere else. The point estimate for birth weight presented in Table 19, on the other hand, implies less than 0.02 gram per well decrease in state average birthweight for Pennsylvania. This calculation takes into consideration that a little over half of the counties in Pennsylvania has at least one new unconventional well drilled over the time period we study.

Table 20 shows the point estimates for the effect on birth outcomes of the number of new fracking wells in a model that allows these effects to differ across rural and urban areas. The results in the first column indicate that the estimated effect on birth weight is negative and statistically significant for both rural and urban areas, but the magnitude of the estimate is larger for births in rural areas.

The association between unconventional drilling and adverse birth outcomes appears to be stronger for rural areas. This suggests that the main mechanism through which hydraulic fracking affects birth outcomes may be water contamination. As reviewed earlier, unconventional drilling is thought to result in groundwater contamination, and larger proportions of rural populations rely on groundwater resources for drinking water. Therefore, mothers in rural areas are at a greater risk of exposure to harmful pollutants through contaminated drinking water, at least compared to mothers in urban areas who typically consume

TABLE 20. Differential effects on birth outcomes in rural and urban counties

	Birth weight	Gestational age	APGAR	Low birth weight	Pre-term
Rural - Unconv.	-0.03868**	-0.00014	-0.00001	-0.00285	0.01314
wells drilled	[0.01623]	[0.00008]	[0.00011]	[0.00705]	[0.01164]
Urban - Unconv.	-0.02103*	0.00003	0.00051	0.00651	-0.00375
wells drilled	[0.01138]	[0.00007]	[0.00048]	[0.00504]	[0.00733]
N	5,588	5,587	4,952	5,588	5,587
R^2	0.128	0.075	0.023	0.04	0.026
# of counties	509	509	509	509	509
Mean	3280	38.67	8.808	65.7	112.3
SD	110.6	0.408	0.381	36.16	51.61

Notes: See notes to Table 19
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

treated water provided through public water systems that are tested regularly for compliance with safe drinking water standards.

The results presented in Table 19 and Table 20 are robust to how wells with no reservoir information are treated.[5] They are also robust to using models with more restrictive assumptions. In particular, the point estimates for the coefficient on the number of new unconventional wells are very similar to the ones presented (and they have similar p-values) in a model with only county fixed effects and a model with county fixed effects and linear time trends.[6]

[5] When we exclude the wells without the reservoir information from the analysis, the point estimates are almost identical to the ones presented. When we assume wells without reservoir information are unconventional wells if they are drilled in a shale county, and conventional wells if they are drilled in a non-shale county the point estimates are slightly smaller and p-values are somewhat larger. But there is no qualitative change in the results.

[6] Appendix Figure 9 displays the point estimates for the coefficient on the number of new unconventional wells in a range of specifications for all birth outcomes considered in Table 19. These specifications range from the most restrictive one with no fixed effects to the one displayed in Table 19.

The effects of unconventional drilling on health, if there are any, are likely to be greater for populations living in areas where drilling activity is more highly concentrated. By choosing the number of unconventional wells as the key independent variable, we implicitly assume that a given number of wells drilled in a relatively small county have the same environmental impact as the same number of wells drilled in a relatively large county. To account for the spatial density of drilling activity, new unconventional wells drilled per thousand square miles in a given county-year is used as the key independent variable in regression equation 4.2. The point estimates are presented in Table 21 and Table 22. These results suggest a stronger negative association between birth weight and unconventional drilling for rural areas than the point estimate presented earlier in Table 20 suggests. However, the point estimates also suggest that there is a positive association between birth outcomes and drilling activities in urban counties.

TABLE 21. Effects of number of unconventional wells drilled per thousand square mile on birth outcomes

	Birth weight	Gestational age	APGAR	Low birth weight	Pre-term
Unconv. wells drilled (per 1000 sqm)	-0.0214 [0.02112]	0.00005 [0.00012]	0.00108* [0.00064]	-0.002 [0.00441]	-0.00139 [0.01197]
N	5,588	5,587	4,952	5,588	5,587
R^2	0.128	0.075	0.022	0.04	0.026
# of counties	509	509	509	509	509
Mean	3280	38.67	8.808	65.7	112.3
SD	110.6	0.408	0.381	36.16	51.61

Notes: All regressions include controls, county fixed effects, and year fixed effects.
Robust standard errors in brackets, clustered at county level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

TABLE 22. Differential effects on birth outcomes in rural and urban counties (Using the number of unconventional wells drilled per thousand square mile as the key independent variable)

	Birth weight	Gestational age	APGAR	Low birth weight	Pre-term
Rural - Unconv. wells	-0.06349**	-0.0002	0.00005	-0.00817	0.02673
drilled (per 1000 sqm)	[0.03147]	[0.00020]	[0.00020]	[0.01286]	[0.02288]
Urban - Unconv. wells	-0.00225	0.00016*	0.00158**	0.0008	-0.01419*
drilled (per 1000 sqm)	[0.01580]	[0.00008]	[0.00068]	[0.00322]	[0.00726]
N	5,588	5,587	4,952	5,588	5,587
R^2	0.128	0.075	0.023	0.04	0.026
# of counties	509	509	509	509	509
Mean	3280	38.67	8.808	65.7	112.3
SD	110.6	0.408	0.381	36.16	51.61

Notes: See notes to Table 19

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

In general, we may expect a newly-drilled unconventional well in a relatively small county to have a larger adverse effect on health compared to the effect of a new well in a relatively large county because one more well in a small county implies a larger change in the density of wells compared to one more well in a large county. Therefore, one approach to interpreting point estimates given in Table 22 would involve scaling up the point estimates for small counties and scaling them down for large counties. Having one more unconventional well drilled in a small rural county that is 600 square miles large in area, for instance, implies about a 0.1 gram decrease in average birth weight. This is calculated by dividing the point estimate given in the first column of Table 22 by 0.6.[7]

One issue in using the number of unconventional wells per square mile as a regressor is that it assumes that the wells drilled in a given county, as well as

[7] 600 square miles is the cutoff for the bottom decile of area for rural counties.

the people living in the same county, have a uniform spatial distribution. This may be a very strong assumption (arguably at least as strong as assuming a uniform distribution for the impacts across counties). An improved measure of exposure to drilling and the associated pollution at the individual level could be number of wells in a close proximity to each individual. However, this would require information on the exact location of each individual. This information is not available in the data set used in this paper.

Conclusion

Over the last fifteen years, there has been a rapid expansion of unconventional oil and natural gas development (UONGD) in the U.S. Unconventional oil and gas resource exploitation has been heavily promoted, based on the potential contributions of these resources to energy independence, their local and national economic benefits, and the fact that natural gas is a cleaner source of energy in terms of greenhouse gas emissions. However, this rapid increase in the intensity of unconventional drilling activity has also raised public health concerns for the local communities. The chemicals used in hydraulic fracturing are known to be harmful to human health, and there is substantial evidence in the literature documenting that unconventional drilling can be linked to water and air pollution.

In this study, we seek to understand the potential adverse health impact that UONGD may have on infant health. We use county-level data on birth outcomes and unconventional drilling in five states that have experienced substantial expansion in UONGD in recent years. Our findings indicate that there is a systematic decrease in birth weight associated with the number of unconventional wells drilled in a given county-year. The magnitude of the estimated effect is very small, but this may be a result of offsetting changes in the sociodemographic composition of the cohort of mothers associated with UONGD. Our results indicate that, associated with unconventional drilling, there is an increase in the fraction of mothers with a college education and a decrease in the fraction of mothers with less than a high school education. The endogeneity of maternal sociodemographics may translate into improvements in observed birth outcomes and offset the negative estimated impact that fracking may have on health at birth.

The county-level aggregation in the data may also contribute to small point estimates. If the adverse impact of fracking is very localized, then considering the changes in the county averages may not reveal the true impact on births to mothers with the highest exposure to fracking and the associated pollution, even if it is very large.

Although the change in educational composition of mothers is observed only in rural areas, the link between unconventional drilling and inferior birth outcomes appears to be stronger for these counties. This suggests that water contamination could be the mechanism behind the negative impact that fracking appears to have on health at birth.

It is predicted that the expansion in UONGD will continue over the next few decades. There have been policy discussions about the initiation or strengthening of regulations, and enhanced monitoring efforts, to control pollution resulting from unconventional drilling. The results found in this study suggest that policies that are designed to regulate emissions and mitigate the risks of UONGD may have measurable health benefits. Further scientific research is needed to guide how the potential risks of fracturing can best be mitigated, and further economic research is necessary to address the social benefits from mitigation policies and how they compare to social costs.

CHAPTER V

CONCLUSION

There is a strong association between an individual's birth outcomes and their future wellbeing. The main goal of the research described in this dissertation is to quantify the systematic effects of behavioral and environmental factors on birth outcomes. The overarching objective is to improve our ability to identify and implement appropriate policies to improve birth outcomes.

In Chapter II, the effectiveness of posted point-of-sale warnings in reducing alcohol consumption among pregnant women is assessed. The findings indicate a statistically significant reduction in women's odds of drinking alcohol during pregnancy in response to alcohol warning signs (AWS) laws, which suggests that AWS may be an effective policy tool in reducing prenatal alcohol exposure. Using the change in alcohol consumption associated with AWS laws, which are arguably exogenous to birth outcomes, the possible causal link between prenatal alcohol exposure and birth outcomes is also considered. I find that AWS laws are associated with statistically significant decreases in the odds of very low birth weight and very pre-term births, which implies that the link between prenatal alcohol use and inferior birth outcomes may be causal.

In Chapter III, some of the potential adverse impacts of climate change on infant health are considered. Using a set of monthly panel data on birth outcomes and heat waves for all U.S. counties over the time period from 1989 to 2008, I find that exposure to heat waves during pregnancy seems to be related to complications in both the mother's and the newborn's health. In particular, heat waves during the second trimester of pregnancy are associated with a slight but statistically significant decrease in average gestational age. Moreover, exposure to heat waves during pregnancy is also related to an increase in the fraction of babies with abnormal conditions related to maternal stress, and an increase in the fraction of mothers who experience a pregnancy-related health condition. Identifying and quantifying the magnitude and the timing of the effects of changing weather conditions on infant health is extremely important in shaping policies related to climate change. Social interventions designed to mitigate the risks from extreme weather related to climate change might be optimally targeted towards pregnant women and/or young children.

Chapter IV focuses on the potential adverse health impact that unconventional oil and natural gas development (UONGD) may have on infants. Using county-level data on birth outcomes and unconventional drilling activity in states that have experienced substantial expansion in UONGD in recent years, I find that birth weights exhibit a negative association with unconventional drilling activity in the same county. This effect appears to be more pronounced in rural areas, although a change in composition of mothers in rural areas also occurs, and these changes would tend to lead to improvements in observed birth outcomes. The effect suggested by the findings in this study is very small in magnitude. However, one reason for this may be level of aggregation in the data. Considering that UONGD activity is expected to continue to grow over the next few decades, the potential adverse impacts of such development on health requires further investigation. The findings from this analysis suggest the presence of statistically significant negative impacts that warrant further research to improve our understanding of their size and importance. In particular, it seems important to pursue more finely disaggregated data that may be less inclined to obscure important effects at geographical scales finer than the entire counties.

APPENDIX

ADDITIONAL TABLES AND FIGURES

TABLE 23. Data availability on alcohol consumption in Vital Statistics data by state and year

	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06
AL	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AK*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
AZ*	x	x	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
AR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
CA*																		
CO	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
CT	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
DE*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
DC*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FL	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
GA*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
HI	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
ID	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
IL*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
IN	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
IA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
KS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
KY*	x	x	x	X	X	X	X	X	X	X	X	X	X	X	X			
LA		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
ME	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MD	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MI	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MN*	x	x	x	x	x	x	x	X	X	X	X	X	X	X	X	X	X	X
MS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MO*	x	x	x	x	x	x	x	x	x	x	x	x	X	X	X	X	X	X
MT	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
NE*		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
NV*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X	X	X	X
NH*	x	x	X	X	X	X	X	X	X	X	X	X	X	X	X			
NJ*	x	x	x	x	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NM*	x	x	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NY*				X	X	X	X	X	X	X	X	X	X	X	X			
NC*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X	X	X	X
ND	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
OH	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
OK			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
OR*	x	x	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PA	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
RI	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SC	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
SD*												X	X	X	X	X	X	
TN*	x	x	x	x	x	x	x	x	X	X	X	X	X	X	X			
TX*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
UT*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
VT	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
VA	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WA*	x	x	x	x	X	X	X	X	X	X	X	X	X	X				
WV*	x	x	x	x	x	x	x	x	x	X	X	X	X	X	X	X	X	X
WI	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WY	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	

* States that have AWS laws.
Data availability in years after AWS laws are passed are indicated by capital X.

TABLE 24. Data availability on alcohol consumption in BRFSS by state and year

State	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
AL		x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x
AK*							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
AZ*	x	x	x	x	x	x	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X
AR							x		x		x		x		x		x	x	x	x	x	x	x	x	x	x
CA*	x	X	X	X	X	X	X	X	X		X	X	X		X		X	X	X	X	X	X	X	X	X	X
CO						x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
CT	x			x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
DE*						X	X	X	X		X		X		X		X	X	X	X	X	X	X	X	X	X
DC*	X	X	X	X	X	X	X	X	X	X			X	X	X		X	X	X	X	X	X	X	X	X	X
FL	x	x	x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
GA*	x	X	X	X	X	X	X	X	X		X		X		X		X	X	X	X	X	X	X	X	X	X
HI		x	x	x	x	x	x	x	x		x		x		x		X	X	X		X	X	X	X	X	X
ID	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
IL*	x	x	x	x	X	X	X	X	X		X*	X*	X*	X*	X*	X*	X	X	X	X	X	X	X	X	X	X
IN	x	x	x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
IA				x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
KS								x	x	x	x		x		x		x	x	x	x	x	x	x	x	x	x
KY*	x	x	x	x	x	x	x	X	X		X	X*	X	X	X		X	X	X	X	X	X	X	X	X	X
LA						X	X	X	X		x		x		x		x	x	x	x	x	x	x	x	x	x
ME			x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
MD			x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
MA		x	x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
MI				x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
MN*	x	x	x	x	x	x	x	x	x	x	x	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MS						x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
MO*		x	x	x	x	x	x	x	x		x		x		x		X	X	X	X	X	X	X	X	X	X
MT	x	x	x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
NE*			x	x	X	X	X	X	X		X		X		X		X	X	X	X	X	X	X	X	X	X
NV*								x	x		x	x	x	x	x	x	x	x	X	X	X	X	X	X	X	X
NH*			x	x	x	x	X	X	X		X		X		X		X	X	X	X	X	X	X	X	X	X
NJ*							x	x	X		X	X	X		X		X	X	X	X	X	X	X	X	X	X
NM*		x	x	x	x	x	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
NY*	x	x	x	x	x	x	X	X	X		X	X	X		X		X	X	X	X	X	X	X	X	X	X
NC*	x	x	x	x	x	x	x	x	x		x		x		x		x	x	X	X	X	X	X	X	X	X
ND	x	x	x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
OH	x	x	x	x	x	x	x	x	x		x		x		x	x	x	x	x	x	x	x	x	x	x	x
OK				x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
OR*					x	x	X	X	X		X		X		X		X	X	X	X	X	X	X	X	X	X
PA					x	x	x	x	x		x	x	x		x		x	x	x	x	x	x	x	x	x	x
RI	x	x	x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x

TABLE 24 continued.

State	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
SC	x	x	x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
SD*			X	X	X	X	X	X	X		X		X		X		X	X	X	X	X	X	X	X	X	X
TN*	x	x	x	x	x	x	x	x	x	x*	x	x*	X	X*	X	X	X	X	X	X	X	X	X	X	X	X
TX*			x	x	x	x	x	x	x		x		x		x	x	x	x	x	x	x	x	X	X	X	X
UT*	x	x	x	x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
VT						x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
VA					x	x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x
WA*			x	x	x	x	x	x	X		X		X		X		X	X	X	X	X	X	X	X	X	X
WV*	x	x	x	x	x	x	x	x	x	x	x		x		X		X	X	X	X	X	X	X	X	X	X
WI	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WY										x	x	x	x		x		x	x	x	x	x	x	x	x	x	x

TABLE 25. Whether (1) had FAS, (2) had low Apgar score, (3) mother smoked during pregnancy.

	(1) FAS		(2) Low Apgar		(3) Maternal Smoking	
AWS	-0.00003	-0.00004	-0.00029	-0.00002	0.00527*	-0.00077
	[0.00002]	[0.00003]	[0.00021]	[0.00024]	[0.00305]	[0.00177]
N	22,213,175	22,213,175	36,616,113	36,616,113	23,695,742	23,695,742
R^2	0	0	0.002	0.002	0.084	0.084
Mean	0.00008	0.00008	0.006	0.006	0.107	0.107
Std. Dev.	0.009	0.009	0.076	0.076	0.309	0.309
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
State-specific trends	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic

Robust standard errors in parentheses, clustered at state level.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

TABLE 26. Whether (1) had low birth weight, (2) had very low birth weight, (3) was pre-term, (4) was very pre-term. Robustness to time period used.

	(1) Low Birth Weight <2500g		(2) Very Low Birth Weight <1500g		(3) Pre-term <37 weeks		(4) Very pre-term <32 weeks	
1989-2006								
AWS	-0.0015	-0.0017**	-0.0006*	-0.0007***	-0.0022*	-0.0008	-0.0011***	-0.0009***
	[0.0011]	[0.0007]	[0.0003]	[0.0002]	[0.0011]	[0.0015]	[0.0003]	[0.0003]
N	32,623,067	32,623,067	32,623,067	32,623,067	28,964,289	28,964,289	28,964,289	28,964,289
R^2	0.011	0.012	0.004	0.004	0.01	0.01	0.005	0.005
Mean	0.0695	0.0695	0.0126	0.0126	0.107	0.107	0.016	0.016
Std. Dev.	0.254	0.254	0.112	0.112	0.309	0.309	0.125	0.125
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific trends	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic

TABLE 26 contiued.

	(1) Low Birth Weight <2500g		(2) Very Low Birth Weight <1500g		(3) Pre-term <37 weeks		(4) Very pre-term <32 weeks	
1985-2010								
AWS	0.0000	-0.0008	-0.0001	-0.0003**	-0.0017	-0.0008	-0.0004	-0.0005**
	[0.0010]	[0.0006]	[0.0003]	[0.0002]	[0.0011]	[0.0011]	[0.0003]	[0.0002]
N	44,421,253	44,421,253	44,421,253	44,421,253	39,346,581	39,346,581	39,346,581	39,346,581
R^2	0.011	0.011	0.004	0.004	0.01	0.01	0.005	0.005
Mean	0.0704	0.0704	0.0126	0.0126	0.107	0.107	0.0161	0.0161
Std. Dev.	0.256	0.256	0.112	0.112	0.309	0.309	0.126	0.126
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific trends	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic

Robust standard errors in parentheses, clustered at state level.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

TABLE 27. Effects of number of unconventional wells drilled on birth outcomes - Controls for educational composition of mothers included

	Birth weight	Gestational age	APGAR	Low birth weight (<2500g)	Pre-term (<37 weeks)
Unconventional wells drilled	-0.03099*** [0.01144]	-0.00005 [0.00007]	0.00031 [0.00030]	0.00366 [0.00277]	0.00452 [0.00781]
N	5,588	5,587	4,952	5,588	5,587
R^2	0.133	0.079	0.023	0.043	0.03
# of counties	509	509	509	509	509
Mean	3280	38.67	8.808	65.7	112.3
SD	110.6	0.408	0.381	36.16	51.61

Notes: All regressions include controls, county fixed effects, and year fixed effects.
Robust standard errors in brackets, clustered at county level.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Model 1: No fixed effect, Model 2: County fixed effects only, Model 3: County fixed effects and quadratic time trends, Model 4: County and year fixed effects

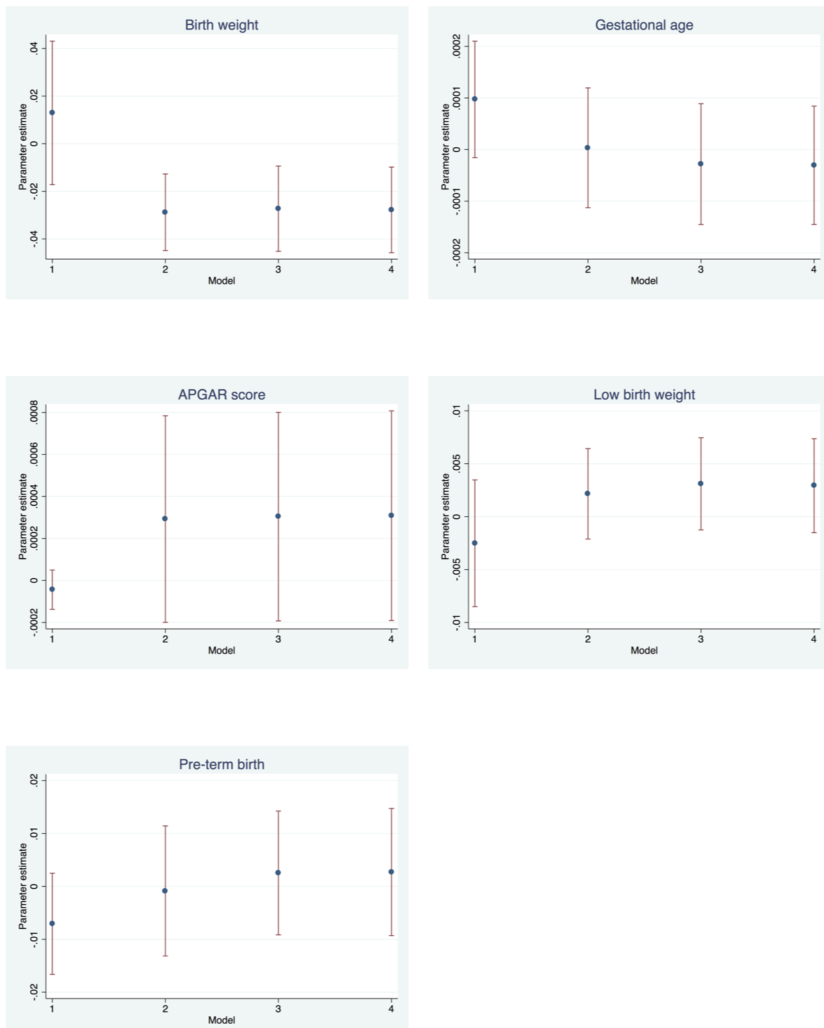

FIGURE 9. Estimates for the coefficient on the number of unconventional wells drilled across different models

REFERENCES CITED

Agostinelli, G. and Grube, J. W. (2002). Alcohol counter-advertising and the media. *Alcohol Research and Health*, 26(1):15–21.

Almond, D. (2006). Is the 1918 influenza pandemic over? longterm effects of in utero influenza exposure in the post1940 u.s. population. *Journal of Political Economy*, 114(4):672–712.

Almond, D., Chay, K. Y., and Lee, D. S. (2005). The costs of low birth weight. *The Quarterly Journal of Economics*, 120(3):1031–1083.

Almond, D. and Currie, J. (2011a). *Human Capital Development before Age Five (Ch. 15 in Handbook of Labor Economics)*. Elsevier.

Almond, D. and Currie, J. (2011b). Killing me softly: The fetal origins hypothesis. *Journal of Economic Perspectives*, 25(3):153–172.

Almond, D. and Mazumder, B. (2005). The 1918 influenza pandemic and subsequent health outcomes: An analysis of sipp data. *The American Economic Review*, 95(2):258–262.

Ananth, C. V., Peedicayil, A., and Savitz, D. A. (1995). Effect of hypertensive diseases in pregnancy on birthweight, gestational duration, and small-or-gestational-age births. *Epidemiology*, 6(4):391–395.

Anderson, C. A. (2001). Heat and violence. *Current Directions in Psychological Science*, 10(1):33–38.

Argo, J. and Main, K. (2004). Meta-analyses of the effectiveness of warning labels. *Journal of Public Policy and Marketing*, 23(2):193–208.

Bamberger, M. and Oswald, R. E. (2012). Impacts of gas drilling on human and animal health. *New Solutions: A Journal of Environmental and Occupational Health Policy*, 22(1):51–77.

Barreca, A. and Page, M. (2012). A pint for a pound? reevaluating the relationship between minimum drinking age laws and birth outcomes. Unpublished Working Paper.

Barry, K., Caetano, R., Chang, G., DeJoseph, M., Miller, L., O'Connor, M., Olson, H., Floyd, R., Weber, M., DeStefano, F., Dolina, S., and Leeks, K. (2009). Reducing alcohol exposed pregnancies: A report of the national task force on fetal alcohol syndrome and fetal alcohol effect. National Task Force on Fetal Alcohol Syndrome and Fetal Alcohol Effect, Atlanta, GA: Centers for Disease Control and Prevention.

Beltran, A. J., Wu, J., and Laurent, O. (2013). Associations of meteorology with adverse pregnancy outcomes: A systematic review of preeclampsia, preterm birth and birth weight. *International journal of environmental research and public health*, 11(1):91–172.

Browning, C. R., Wallace, D., Feinberg, S. L., and Cagney, K. A. (2006). Neighborhood social processes, physical conditions, and disaster-related mortality: the case of the 1995 chicago heat wave. *American Sociological Review*, 71(4):661–678.

Butke, P. and Sheridan, S. C. (2010). An analysis of the relationship between weather and aggressive crime in cleveland, ohio. *Weather, Climate, and Society*, 2(2):127–139.

Card, D. and Dahl, G. B. (2011). Family violence and football: The effect of unexpected emotional cues on violent behavior. *The Quarterly Journal of Economics*, 126(1):103–143.

Carolan-Olah, M. and Frankowska, D. (2014). High environmental temperature and preterm birth: A review of the evidence. *Midwifery*, 30(1):50–59.

CDC (2004). *Fetal Alcohol Syndrome: Guidelines for Referral and Diagnosis.* National Task Force on Fetal Alcohol Syndrome and Fetal Alcohol Effect, Atlanta, GA.

CDPHE (2009). Garfield county emissions inventory. Colorado Department of Public Health and Environment. http://www.garfield-county.com/air-quality/documents/airquality/Garfield_County_Emissions_Inventory-2009.pdf (Accessed May 2015), Colorado, US.

Colborn, T., Kwiatkowski, C., Schultz, K., and Bachran, M. (2011). Natural gas operations from a public health perspective. *Human and Ecological Risk Assessment: An International Journal*, 17(5):1039–1056.

Currie, J. (2009). Healthy, wealthy, and wise: Socioeconomic status, poor health in childhood, and human capital development. *Journal of Economic Literature*, 47(1):87–122.

Currie, J. (2011). Inequality at birth: Some causes and consequences. *American Economic Review*, 101(3):1–22.

Currie, J. and Rossin-Slater, M. (2012). Weathering the storm: Hurricanes and birth outcomes. *National Bureau of Economic Research Working Paper Series*, (18070).

Currie, J. and Schmieder, J. F. (2009). Fetal exposures to toxic releases and infant health. *The American Economic Review Papers and Proceedings*, 99(2):177–183.

Currie, J. and Schwandt, H. (2013). Within-mother analysis of seasonal patterns in health at birth. *Proceedings of the National Academy of Sciences of the United States of America*, 110(30).

Currie, J. and Walker, W. R. (2011). Traffic congestion and infant health: Evidence from e-zpass. *American Economic Journal: Applied Economics*, 3(1):65–90.

Dadvand, P., Parker, J., Bell, M., Bonzini, M., Brauer, M., Darrow, L., Gehring, U., Glinianaia, S., Gouveia, N., Ha, E., et al. (2013). Maternal exposure to particulate air pollution and term birth weight: a multi-country evaluation of effect and heterogeneity. *Environmental Health Perspectives*, 121(3):267–373.

Dehejia, R. and Lleras-Muney, A. (2004). Booms, busts, and babies' health. *The Quarterly Journal of Economics*, 119(3):1091–1130.

Dejmek, J., Solanskỳ, I., Benes, I., Lenícek, J., and Srám, R. J. (2000). The impact of polycyclic aromatic hydrocarbons and fine particles on pregnancy outcome. *Environmental Health Perspectives*, 108(12).

Deschênes, O., Greenstone, M., and Guryan, J. (2009). Climate change and birth weight. *The American Economic Review*, 99(2):211–217.

Deshpande, S., Basil, M., Basford, L., Thorpe, K., Piquette-Tomei, N., Droessler, J., Cardwell, K., Williams, R., and Bureau, A. (2005). Promoting alcohol abstinence among pregnant women. *Health Marketing Quarterly*, 23(2):45–67.

Dikensoy, E., Balat, O., Cebesoy, B., Ozkur, A., Cicek, H., and Can, G. (2009). The effect of ramadan fasting on maternal serum lipids, cortisol levels and fetal development. *Archives of Gynecology and Obstetrics*, 279(2):119–123.

DOE (2013). Natural gas from shale: Questions and answers. U.S. Department of Energy. http://energy.gov/sites/prod/files/2013/04/f0/how_is_shale_gas_produced.pdf (Accessed May 2015).

Duneier, M. (2006). Ethnography, the ecological fallacy, and the 1995 chicago heat wave. *American Sociological Review*, 71(4):679–688.

Ehrlich, M., Harville, E., Xiong, X., Buekens, P., Pridjian, G., and Elkind-Hirsch, K. (2010). Loss of resources and hurricane experience as predictors of postpartum depression among women in southern louisiana. *Journal of Womens Health*, 19(5):877–884.

EIA (2013). Technically recoverable shale oil and shale gas resources: An assessment of 137 shale formations in 41 countries outside the united states. U.S. Energy Information Administration. http://www.eia.gov/analysis/studies/worldshalegas/pdf/fullreport.pdf (Accessed May 2015), Washington, D.C.

EIA (2015). Annual energy outlook 2015 with projections to 2040. Technical report, U.S. Energy Information Administration, Washington, D.C.

EPA (2008). An assessment of the environmental implications of oil and gas production: A regional case study. U.S. Environmental Protection Agency, Washington, D.C.

EPA (2011). Investigation of ground water contamination near pavillion, wyoming. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Ada, OK.

Fenaughty, A. and MacKinnon, D. (1993). Immediate effects of the arizona alcohol warning poster. *Journal of Public Policy and Marketing*, 12(1):69–77.

Fertig, A. and Watson, T. (2009). Minimum drinking age laws and infant health outcomes. *Journal of Health Economics*, 28(3):737–747.

Greenfield, T. and Kaskutas, L. (1998). Five years' exposure to alcohol warning label messages and their impacts: Evidence from diffusion. *Applied Behavioral Science Review*, 6(1):39.

Hankin, J., Firestone, I., Sloan, J., Ager, J., Goodman, A., Sokol, R., and Martier, S. (1993). The impact of the alcohol warning label on drinking during pregnancy. *Journal of Public Policy and Marketing*, 12(1):10–18.

Hankin, J., Sloan, J., and Sokol, R. (1998). The modest impact of the alcohol beverage warning label on drinking during pregnancy among a sample of african-american women. *Journal of Public Policy and Marketing*, 17(1):61–69.

Harville, E. W., Tran, T., Xiong, X., and Buekens, P. (2010a). Population changes, racial/ethnic disparities, and birth outcomes in louisiana after hurricane katrina. *Disaster Medicine and Public Health Preparedness*, 4:S39–S45.

Harville, E. W., Xiong, X., and Buekens, P. (2010b). Disasters and perinatal health: A systematic review. *Obstetrical and Gynecological Survey*, 65(11):713–728.

Harville, E. W., Xiong, X., Pridjian, G., Elkind-Hirsch, K., and Buekens, P. (2009). Postpartum mental health after hurricane katrina: A cohort study. *BMC pregnancy and childbirth*, 9(1):21.

Hill, E. L. (2013). Shale gas development and infant health: evidence from pennsylvania. Working Paper, The Charles H. Dyson School of Applied Economics and Management, Cornell University, WP 2012-12.

Holladay, J. S. and LaRiviere, J. (2013). The effect of abundant natural gas on air pollution from electricity production. Unpublished Working Paper.

Kalsher, M. J., Clarke, S. W., and Wogalter, M. S. (1993). Communication of alcohol facts and hazards by a warning poster. *Journal of Public Policy and Marketing*, 12(1):78–90.

Kesmodel, U., Olsen, S. F., and Secher, N. J. (2000). Does alcohol increase the risk of preterm delivery? *Epidemiology*, 11(5):512–518.

Klinenberg, E. (2003). *Heat wave: A social autopsy of disaster in Chicago*. University of Chicago Press.

Krupnick, A. (2013). *Managing the Risks of Shale Gas: Key Findings and Further Research*. Resources for the Future.

Laaidi, M., Boumendil, A., Tran, T. C., Kaba, H., Rozenberg, P., and Aegerter, P. (2011). Effects of meteorological conditions on pregnancy outcome: Literature review. *Environnement Risques and Sante*, 10(2):128–141.

Lavaine, E. and Neidell, M. J. (2013). Energy production and health externalities: Evidence from oil refinery strikes in france. National Bureau of Economic Research Working Paper No. w18974.

Lee, C. (2014). Intergenerational health consequences of in utero exposure to maternal stress: Evidence from the 1980 kwangju uprising. *Social Science and Medicine*, in press.

Lindo, J. M. (2011). Parental job loss and infant health. *Journal of Health Economics*, 30(5):869–879.

Litovitz, A., Curtright, A., Abramzon, S., Burger, N., and Samaras, C. (2013). Estimation of regional air-quality damages from marcellus shale natural gas extraction in pennsylvania. *Environmental Research Letters*, 8(1).

MacKinnon, D., Nohre, L., Cheong, J., Stacy, A., and Pentz, M. (2001). Longitudinal relationship between the alcohol warning label and alcohol consumption. *Journal of Studies on Alcohol*, 62:221–227.

MacKinnon, D. P., Williams-Avery, R. M., Wilcox, K. L., and Fenaughty, A. M. (1999). Effects of the arizona alcohol warning poster. *Journal of Public Policy and Marketing*, 18(1):77–88.

Maniloff, P. and Mastromonaco, R. (2014). The local economic impacts of hydraulic fracturing and determinants of dutch disease. Unpublished Working Paper.

Martin, J., Hamilton, B., Sutton, P., Ventura, S., Menacker, F., and Munson, M. (2003). National vital statistics reports 2003. National Center for Health Statistics, Hyattsville, MD. Vol.52, No. 10.

McKenzie, L. M., Guo, R., Witter, R. Z., Savitz, D. A., Newman, L. S., and Adgate, J. L. (2014). Birth outcomes and maternal residential proximity to natural gas development in rural colorado. *Environmental Health Perspectives*, 122(4):412–7.

McKenzie, L. M., Witter, R. Z., Newman, L. S., and Adgate, J. L. (2012). Human health risk assessment of air emissions from development of unconventional natural gas resources. *Science of the Total Environment*, 424:79–87.

Metz, B., Davidson, O., Bosch, P., Dave, R., and Meyer, L. (2007). *Climate change 2007: Mitigation of climate change. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.

Murray, B. C., Maniloff, P., and Murray, E. (2014). Why have greenhouse emissions in rggi states declined? an econometric attribution to economic, energy market, and policy factors. Duke Environmental and Energy Economics Working Paper Series, No. EE 14–01.

NCHS (1992). Public use data tape documentation, 1989 detail natality. National Center for Health Statistics, Hyattsville, MD.

NCHS (2012). Healthy people 2010 final review. National Center for Health Statistics. http://www.cdc.gov/nchs/data/hpdata2010/hp2010_final_review.pdf, Hyattsville, MD.

NETL (2013). Modern shale gas development in the united states: An update. U.S. Department of Energy, National Energy Technology Laboratory Strategic Center for Natural Gas and Oil.

Okun, M. L., Roberts, J. M., Marsland, A. L., and Hall, M. (2009). How disturbed sleep may be a risk factor for adverse pregnancy outcomes. *Obstetrical and Gynecological Survey*, 64(4):273–80.

Olmstead, S. M., Muehlenbachs, L. A., Shih, J.-S., Chu, Z., and Krupnick, A. J. (2013). Shale gas development impacts on surface water quality in pennsylvania. *Proceedings of the National Academy of Sciences*, 110(13):4962–4967.

Osborn, S. G., Vengosh, A., Warner, N. R., and Jackson, R. B. (2011). Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences*, 108(20):8172–8176.

Pachauri, R. and Reisinger, A. (2007). Climate change 2007: Synthesis report. contribution of working groups i, ii and iii to the fourth assessment report of the intergovernmental panel on climate change. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Perry, S. L. (2013). Using ethnography to monitor the community health implications of onshore unconventional oil and gas developments: examples from pennsylvania's marcellus shale. *New Solutions: A Journal of Environmental and Occupational Health Policy*, 23(1):33–53.

Ponicki, W. (2004). Statewide availability data system ii: 1933-2003. National Institute on Alcohol Abuse and Alcoholism Research Center Grant P60-AA006282-23, Berkeley, CA: Pacific Institute for Research and Evaluation, Prevention Research Center.

Schaller, J. (2015). Booms, busts, and fertility: Testing the becker model using gender-specific labor demand. *Journal of Human Resources*, forthcoming.

Scheraga, J., Ebi, K., Furlow, J., and Moreno, A. (2003). *From science to policy: developing responses to climate change (Ch. 12 in Climate Change and Human Health: Risks and Responses)*. Geneva, Switzerland.

Schifano, P., Lallo, A., Asta, F., De Sario, M., Davoli, M., and Michelozzi, P. (2013). Effect of ambient temperature and air pollutants on the risk of preterm birth, rome 2001-2010. *Environment International*, 61:77–87.

SHELDUS (2013). The spatial hazard events and losses database for the united states. Hazards and Vulnerability Research Institute, On-line database, Version 10.1.

Simeonova, E. (2011). Out of sight, out of mind? natural disasters and pregnancy outcomes in the usa. *CESifo Economic Studies*, 57(3):403–431.

Slama, R., Thiebaugeorges, O., Goua, V., Aussel, L., Sacco, P., Bohet, A., Forhan, A., Ducot, B., Annesi-Maesano, I., Heinrich, J., et al. (2009). Maternal personal exposure to airborne benzene and intrauterine growth. *Environmental Health Perspectives*, 117(8):1313–21.

Sokol, R. J., Delaney-Black, V., and Nordstrom, B. (2003). Fetal alcohol spectrum disorder. *JAMA*, 290(22):2996–2999.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., Tignor, M., and Miller, H. (2007). Climate change 2007: The scientific basis. contribution of working group i to the fourth assessment report of the intergovernmental panel on climate change. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Steinzor, N., Subra, W., and Sumi, L. (2013). Investigating links between shale gas development and health impacts through a community survey project in pennsylvania. *New Solutions: A Journal of Environmental and Occupational Health Policy*, 23(1):55–83.

Stillerman, K. P., Mattison, D. R., Giudice, L. C., and Woodruff, T. J. (2008). Environmental exposures and adverse pregnancy outcomes: a review of the science. *Reproductive Sciences*, 15(7):631–650.

Strand, L. B., Barnett, A. G., and Tong, S. (2011). The influence of season and ambient temperature on birth outcomes: A review of the epidemiological literature. *Environmental Research*, 111(3):451–462.

Truong, K. D., Reifsnider, O. S., Mayorga, M. E., and Spitler, H. (2012). Estimated number of preterm births and low birth weight children born in the united states due to maternal binge drinking. *Maternal and Child Health Journal*, pages 1–12.

Wang, J., Williams, G., Guo, Y., Pan, X., and Tong, S. (2013). Maternal exposure to heatwave and preterm birth in brisbane, australia. *Bjog-An International Journal of Obstetrics and Gynaecology*, 120(13):1631–1641.

Weber, J. G. (2012). The effects of a natural gas boom on employment and income in colorado, texas, and wyoming. *Energy Economics*, 34(5):1580–1588.

Werner, A. K., Vink, S., Watt, K., and Jagals, P. (2015). Environmental health impacts of unconventional natural gas development: A review of the current strength of evidence. *Science of The Total Environment*, 505:1127–1141.

Whitehead, N. and Lipscomb, L. (2003). Patterns of alcohol use before and during pregnancy and the risk of small-for-gestational-age birth. *American Journal of Epidemiology*, 158(7):654–662.

Wilson, B. J., Watson, M. S., Prescott, G. J., Sunderland, S., Campbell, D. M., Hannaford, P., and Smith, W. C. S. (2003). Hypertensive diseases of pregnancy and risk of hypertension and stroke in later life: results from cohort study. *BMJ: British Medical Journal*, 326(7394):845.

Witter, R. Z., McKenzie, L., Stinson, K. E., Scott, K., Newman, L. S., and Adgate, J. (2013). The use of health impact assessment for a community undergoing natural gas development. *American journal of public health*, 103(6):1002–1010.

Wolf, J. and Armstrong, B. (2012). The association of season and temperature with adverse pregnancy outcome in two german states, a time-series analysis. *Plos One*, 7(7).

Xiong, X., Harville, E. W., Mattison, D. R., Elkind-Hirsch, K., Pridjian, G., and Buekens, P. (2008). Exposure to hurricane katrina, post-traumatic stress disorder and birth outcomes. *American Journal of the Medical Sciences*, 336(2):111–115.

Yang, J., Hartmann, K. E., Savitz, D. A., Herring, A. H., Dole, N., Olshan, A. F., and Thorp, J. M. (2004). Vaginal bleeding during pregnancy and preterm birth. *American Journal of Epidemiology*, 160(2):118–125.

Yang, J. and Savitz, D. (2001). The effect of vaginal bleeding during pregnancy on preterm and small-for-gestational-age births: Us national maternal and infant health survey, 1988. *Paediatric and Perinatal Epidemiology*, 15(1):34–39.

Zahran, S., Snodgrass, J. G., Peek, L., and Weiler, S. (2010). Maternal hurricane exposure and fetal distress risk. *Risk Analysis*, 30(10):1590–1601.

Zahran, S., Weiler, S., Mielke, H. W., and Pena, A. A. (2012). Maternal benzene exposure and low birth weight risk in the united states: A natural experiment in gasoline reformulation. *Environmental Research*, 112:139–146.