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Unconventional Natural Gas Development and Infant Health: Evidence from Pennsylvania

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Abstract

Over the last decade, intensive unconventional natural gas development (NGD) has become prevalent in 31 states. There are numerous environmental and health concerns related to this process, but to date no study has linked natural gas development with human health directly. This research exploits the natural experiment of the gradual introduction of unconventional natural gas wells in the Marcellus Shale to identify the impacts of resulting air and water pollution on infant health. The immediate outcomes of interest are infant health at birth measures (low birth weight, premature birth, small for gestational age and 5 minute APGAR scores). This study examines singleton births to mothers residing close to an unconventional natural gas well from 2003-2010 in Pennsylvania. The difference in differences approach compares birth outcomes before and after a gas well was completed for mothers who live 2.5 km (approx. 1.5 miles) from gas development. The results suggest that exposure to NGD before birth increases the overall prevalence of low birth weight by 25 percent, increases overall prevalence of small for gestational age by 17 percent and reduces 5 minute APGAR scores, while little impact on premature birth is detected.

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I Introduction

The United States (US) holds large unconventional gas reserves in relatively impermeable media such as coalbeds, shale, and tight gas sands. The US and Canada still account for virtually all shale gas produced commercially in the world (IEA, 2012). New technologies, such as hydraulic fracturing and directional drilling, have made it economically and practically feasible to extract natural gas from these previously inaccessible geological formations. Shale gas has been in production for several decades, but started expanding rapidly most recently, growing at more than 45% per year between 2005 and 2010. In 2010, unconventional gas production was nearly 60% of total gas production in the US (IEA, 2012). The number of unconventional natural gas wells in the US rose from 18,485 in 2004 to 25,145 in 2007 and is expected to continue growing through at least 2020 (Vidas and Hugman, 2008). Unconventional natural gas development (NGD) now exists in 31 states and more states are planning to begin drilling in the near future. Most recently, unconventional NGD is underway in Pennsylvania in the Marcellus Shale that spans West Virginia, Pennsylvania, Ohio and New York. Drilling in Pennsylvania began with 20 wells at the end of 2007 and by the end of 2010 there were 4,272 unconventional natural gas wells (DEP, 2010). With this expansion, it is becoming increasingly common for unconventional NGD to take place in close proximity to where people live, work and play.

Unconventional NGD is currently exempted from the Safe Drinking Water Act, Clean Air Act, and Clean Water Act regulations, as well as others. NGD is performed on private land that has been leased to gas companies by individual landowners. Many such leases were signed years before environmental or health concerns emerged. Furthermore, individuals who chose not to lease their land are often surrounded by neighbors who have, and are therefore still vulnerable to any impacts associated with NGD. Serious environmental and health concerns have emerged regarding NGD that may outweigh the perceived benefits of the technique (COGCC, 2009). To shed light on the matter, this research investigates the causal relationship between unconventional NGD and infant health in Pennsylvania.

The causal relationship between unconventional natural gas development and infant health is of interest for four reasons. First, there is a growing body of research linking early exposure to pollution and adverse effects on fetal health[1] and there is increasing evidence of the long-term effects of poor health at birth on future outcomes. For example, low birth weight has been linked to lower educational attainment and future health problems (see Currie (2009) for a summary of this research). The debate over the costs and benefits of unconventional NGD could be significantly impacted by any evidence that suggests natural gas drilling has a damaging effect on fetal health. Second, the study of newborns overcomes several confounding issues in researching the causal relationship between pollution and health because, unlike adult diseases that may reflect pollution exposure that is cumulative, the link between cause and effect is immediate. Third, NGD was defined by the EPA in 2004 as safe and unlikely to cause adverse health outcomes, but growing anecdotal evidence is suggesting otherwise. The political environment from 2005 until 2010 allowed for nationwide regulatory exemptions of NGD. So, although NGD is not randomly assigned to locales, counties or states, it does offer an interesting natural experiment for investigating the effects of pollution on health. Fourth, most of the literature links fetal health impacts to air pollution, but NGD has the potential to increase both air pollution and water pollution. This research may also allow for a natural experiment in which the causal relationship between water pollution and health could also be determined, which has yet to be examined in the literature.

This paper seeks to provide estimates of the health effects of unconventional NGD by examining the effect of the initial introduction of this technology in Pennsylvania that lead to a sharp increase in the prevalence of natural gas wells and drilling development within a relatively short time frame at different spatial locations across Pennsylvania. Unconventional NGD brings with it many potential stressors that may affect a pregnant woman and her expectant baby. NGD requires large quantities of truck traffic, results in loud noise around the clock, requires bright lights for drilling to occur at night, and results in direct and fugitive air emissions of a complex mixture of pollutants from the methane itself as well as diesel engines, drilling muds and tanks that contain produced water and fracturing fluids (Zielinska et al., 2010; Consulting, 2010; Alvarez and Fund, 2009; Sage Environmen-

[1] See Mattison et al. (2003) and Glinianaia et al. (2004a) for a summary of this literature

tal Consulting, 2011). The complex chemicals are associated with many health effects, such as cancers, nervous system impairment and impaired lung function (see McKenzie et al. (2012) for a review of studies investigating the effects of inhalation exposure).

This analysis provides the first estimates of mother exposure to unconventional NGD and subsequent infant health. In an absence of a randomized trial, the introduction of natural gas drilling to a locale is exploited to compare infant outcomes of those living near permitted natural gas activity to those born after said activity has taken place. Specifically, this research compares mothers within a 2.5 km distance of a permit to those within 2.5 km of an existing well in Pennsylvania (defined as “before and after” for simplicity throughout the text).

Pennsylvania is a compelling setting for this particular research design because it is heavily populated and unconventional NGD has only recently begun in 2007. This provides a short window of time for investigation, which reduces other unobserved confounding factors that may be associated with local time trends in infant health. Furthermore, this study utilizes detailed birth certificate records that identify the exact addresses of mothers, in contrast to other observational studies that use a centroid of a geographical area to define exposure and proximity. This information enables a marked improvement in the assignment of pollution exposure.

In the subsequent paper, the difference-in-differences research design, which relies heavily on the assumption that the characteristics of mothers who live close to a permitted well are similar to those who live close to an actual existing well, is tested by examining the observable characteristics of the mothers in these two groups. A range of specifications are estimated in an effort to provide evidence that the research design is robust.

The results suggest both statistically and economically significant effects on infant health. The difference-in-difference models indicate that low birth weight increased by upwards of 25% among mothers within 2.5km of an existing unconventional natural gas well, while the incidence of small for gestational age increased in similar magnitude and average 5 minute APGAR scores were reduced. These are large but not implausible effects given previous studies. In contrast, there are no significant effects of the introduction of natural gas drilling on the prevalence of premature birth or on the demographic characteristics of mothers in the vicinity of an existing well at this 2.5 km radius.

The next section provides background on pollution and infant health, the process of unconventional natural gas drilling, and the associated pollution and health impacts with gas development. Section III describes the data and provides some descriptive statistics. Section IV provides a detailed description of the empirical strategy. Section V presents the results and implements robustness checks. Section VI concludes.

II Background

II.I Air Pollution, Water Pollution and Infant Health

Many studies suggest an association between air pollution and fetal health. Mattison et al. (2003) and Glinianaia et al. (2004a) summarize much of the literature.[2] There is also a large literature linking air pollution and child health. See Schwartz (2004) for a review.

Several previous studies are especially relevant to this research because they focus on "natural experiments." Chay and Greenstone (2003) examine the implementation of the Clean Air Act of 1970. They estimate that a one unit decline in particulates caused by the implementation of the Clean Air Act led to between 5 and 8 fewer infant deaths per 100,000 live births. They also find some evidence that declines in total suspended particles (TSPs) led to reductions in the incidence of low birth weight. Other studies that are similar in nature are a series of papers written by Janet Currie and her co-authors.[3] Currie et al. (2009) examine the effects of several pollutants on fetal health in New Jersey using models that include maternal fixed effects. They find that carbon monoxide is particularly implicated in negative birth outcomes. Currie and Walker (2011) exploit the introduction of E-ZPass in New Jersey and Pennsylvania to identify the impacts of pollution on infant health. They compare mothers near toll plazas to those who live further from toll plazas (but still close to busy roadways). They find that E-ZPass increases both birth weight and gestation length. They obtain similar results when using mother fixed

[2] See Knittel et al. (2011) for a list of more recent papers.

[3] Other related papers include: ambient air pollution in California (Currie and Neidell, 2005), superfund sites (Currie et al., 2011) and Toxic Release Inventories (Currie and Schmieder, 2009).

effects and compare siblings before and after the adoption of E-ZPass. Knittel et al. (2011) provide evidence that air pollution, even at the low levels seen today, is still impacting infant health (their time period of study is 2002-2007). The authors use an instrumental variables approach to exploit the relationship between weather, ambient air pollution and traffic to identify the effects of various pollutants on infant mortality. They find that particulate matter has a large impact on weekly infant mortality rates.

A few studies use natural experiments to address the association between water pollution and fetal, infant or child health. There are two studies to date addressing water pollution and infant mortality, both in the context of India. Greenstone and Hanna (2011) study air and water pollution regulations and find that the water pollution regulations have no measurable impact on water quality, and thus no improvement in infant health. Brainerd and Menon (2011) use seasonal variation of the use of fertilizer to look at water quality impacts on infant and child health. The identification strategy exploits the different planting seasons across regions to identify the impact of agrichemical contamination on measures of child health. The results indicate that those exposed to higher concentrations of agrichemicals during their first trimester experience worse health outcomes.

Although much of the environmental impacts of NGD are suspected to be through the mechanism of water pollution, there is also growing evidence that drilling natural gas wells results in measurable increases in air pollution emissions. Due to a current lack of scientific literature regarding the first stage (direct effect of NGD on air and water pollution and the timing for these), this paper provides evidence of a "composite effect" (combined air and water pollution) on infant health.

II.II Background on Unconventional Natural Gas Development

In Pennsylvania, unconventional natural gas development (NGD) involves vertical and horizontal wells alike and includes a technique to stimulate the wells called hydraulic fracturing. Due to hydraulic fracturing being an essential component of natural gas development, this research focuses on the entire process of NGD. The first natural gas well in the Marcellus Shale was drilled in 2006; most drilling didn't begin until 2008. This paper uses data from 2003 to 2010 to look at the immediate and short-term impacts of natural gas development on infant health in Pennsylvania. The locations where these wells are drilled are mostly rural and have not had other forms of drilling or coal mining.

The administrative process of well completion in Pennsylvania involves many steps. It begins with a gas company's "land men" traveling to property owners offering them royalties in exchange for the use of their property. When a mineral rights owner (this may or may not be the owner of the surface property) leases their land to a gas company, the company usually has a fixed number of years to drill a well on their property. The lease usually involves a signing bonus based on a fixed quantity of money per acre of property leased. These leasing bonuses have increased in magnitude over time. In 2005, they averaged $100 per acre and by 2008, averaged $2,000 per acre (Geology.com, 2012). The lease also includes a stipulation regarding royalties from gas production. The customary royalty rate is 12.5 percent of the value of gas produced by a particular well. Once a lease is signed, the gas company can then approach the state government regarding a permit to drill the well, and once the state approves the permit, the company is free to proceed with drilling.

The entire process of "completing" a natural gas well takes, on average, 3 months to finish.[4] It takes approximately one week for the drilling pad to be prepared, which may require tree clearing and building a foundation for the pad. Then it takes approximately a month for the well to be drilled using a drilling rig. These rigs run non-stop during the drilling process. During this first month, there is heavy diesel truck traffic day and night. Once the well is drilled, a smaller completion rig replaces the drilling rig to do the hydraulic fracturing. This involves injecting 3-4 million gallons of water mixed with sand and chemicals into the well and using a large amount of pressure to fracture the shale about 7,000 ft below the surface (LLC, 2009). Once the well has been fractured, the process of gas production begins. During the first 30 days after well completion, it is estimated that approximately 25-50% of the water used during the NGD process returns to the surface and is collected to be treated at a waste water facility. Often, though, this water will sit in "water impoundments" (ground level lined pits) for some time before it is collected and trucked off to be recycled or treated as waste (STRONGER, 2010).

[4]Please see the appendix for a graphical representation of this process.

It is likely that gas companies choose the leases they take to the state based upon production of existing wells nearby.[5] There are certainly counties in Pennsylvania where the average production of a Marcellus well is higher than other counties and these counties have the highest density of drilled wells. Despite this, gas companies are requesting permits for wells that they ultimately do not drill. Based on permit and drilled well data from the Pennsylvania Department of Environmental Protection (PA DEP), less than 50% of permits become an active well.[6]

Although gas production in the Marcellus shale precipitously declines over the first year after drilling, the quantity of royalties can be substantial. Unfortunately, calculating the average daily production of a well is quite complicated with the current data available from the PA DEP. Some reports indicate that the average horizontal hydraulically fractured Marcellus shale well produces between 1,664 and 2,726 Mcf (or thousands of cubic feet) per day (Kelso, 2011).[7] The 95th percentile of wells produce 22,276 Mcf per day.[8] There are no current estimates of the long term production of wells in this region.

II.III Natural Gas Development As A Potential Pollution Source

Preliminary evidence indicates that NGD produces toxic waste that contaminates the air, aquifers, waterways, and ecosystems that surround drilling sites. Waste also has the potential to contaminate ground water with unknown long term implications. Each shale play has a unique geology, and therefore requires a unique combination of chemicals, sand, pressure, heat and quantity of water to "stimulate" the well.

In April 2011, a Congressional report was released regarding the cocktail of chemicals used in the process (Energy and Committee, 2011). Between 2005 and 2009, the 14 oil and gas service companies reportedly used more than 2,500 hydraulic fracturing products

[5]There are likely to be concerns about well placement being correlated with unobserved variables that can also impact infant health. On the one hand, many reports indicate that there are no potential health risks to living near a well, so parents who sign a lease may be health conscious, and desire to get the income to provide their children the best health care. On the other hand, there are anecdotal stories of health problems and so property owners who choose to lease their land may also be less health conscious. The potential selection into living close to a well could go either way, if these are plausible suggestions.

[6]As of 2/3/2012, according to data from the PA DEP website, there are 4,272 distinct wells drilled in PA and 9,005 active permits (approximately 48% of permits have become active wells)

[7]These figures were calculated by the Kelso (2011) using the PA DEP data used in this study.

[8]These figures are calculated from marcellusmonitor.com data.

containing 750 chemicals and other components. Of these 2,500 products, 650 contained 29 chemicals that are either 1) known or possible human carcinogens 2) regulated under the Safe Drinking Water Act for their risks to human health or 3) listed as hazardous air pollutants under the Clean Air Act. The most widely used chemical was methanol, a hazardous air pollutant. The BTEX compounds - benzene, toluene, xylene, and ethylbenzene - appeared in 60 of the hydraulic fracturing products used between 2005 and 2009. The gas companies injected 11.4 million gallons of products containing at least one BTEX chemical over the five year period reported.

According to a report to the New York Department of Environmental Conservation (NY DEC), the estimated quantity of traffic necessary for well completion is anywhere from 1,500 to over 2,000 truck trips (Consulting, 2010). This traffic is necessary to haul in and out drilling fluids, sand and drilling equipment. Heavy truck traffic and compressor stations are linked to increased air pollution surrounding the well sites. Volatile organic compounds (VOCs), which include BTEX and other hydrocarbons, and fugitive methane gas mix with nitrogen oxides (NO_x) from truck exhaust and produce ground-level ozone. Prenatal exposure to ozone during the 2nd and 3rd trimesters has been associated with low birth weight (Salam et al., 2005).

The Marcellus Shale and the Barnett Shale in Texas contain naturally occurring radioactive material (NORM) which contaminates the flow back fluid and is brought to the surface through the drilling process. The radioactivity of production brine waste from traditional vertical wells drilled into Marcellus Shale was found to be 267 times the recommended EPA levels under the Safe Drinking Water Act (Lustgarten, 2009). A measure of radioactivity from flow back fluid (fluid that returns to the surface post-well completion) is not available, but it is suggested that it is higher than the conventional gas waste.

A growing body of evidence shows that NGD has an impact on ambient air pollution. Emissions inventories for many of the older shale plays are available, such as the Barnett Shale in Texas and the Denver-Julesburg Basin in Colorado (Alvarez and Fund (2009), Bar-Ilan et al. (2008)). The most recent study was conducted in Fort Worth, TX (Sage Environmental Consulting, 2011). The majority of air pollution from drilling is associated with drilling rigs and compressor stations. These studies have calculated estimates of annual total emissions of organic compounds for each of these regions. They have found that the majority of emissions are of pollutants with low toxicities (e.g. methane, ethane, propane and butane), but several pollutants with high toxicities are also being emitted during drilling (e.g. benzene, acrolein and formaldehyde). A study of Texas drilling rigs found that the total amount of combined organic compounds emitted for the year 2008 was 82,251 tons/year for all drilling activity that year.[9] No current studies of this nature exist regarding drilling in the Marcellus shale in Pennsylvania, but these studies provide some evidence for the belief that NGD may be causing air pollution.

II.IV Related Literature on Health and natural gas development

Most of the studies to date that address potential health impacts of NGD measure pollutants at drilling sites or in drilling fluids and then identify the health implications based upon expected exposure to these chemicals. Colborn et al. (2011) find that more than 75% of the chemicals could affect the skin, eyes, and other sensory organs, and the respiratory and gastrointestinal systems. Chronic exposure is particularly concerning because approximately 40-50% 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 mutations. These may have long-term health effects that are not immediately expressed after a well is completed. McKenzie et al. (2012) focuses on the health risk of air emissions from well pads in Colorado. The study collected emissions measurements in Garfield County and then estimated chronic and subchronic non-cancer indices and cancer risks from exposure to the measured emissions for residences less than 1/2 mile and more than 1/2 mile from wells. The study determined that the cancer risks within 1/2 mile of a well are 10 in a million and 6 in a million for those residences greater than 1/2 mile from a well. Benzene was the major contributor to the risk. These results indicate that health effects from air emissions from NGD warrant further study and prospective studies should focus on the health effects associated with air pollution.

[9] This figure combines measurements for CO, NO_x, PM_{10}, SO_2 and VOCs) (Eastern Research Group, 2009). For comparison purposes, and despite the substantial heterogeneity in coal plant emissions, a typical coal plant produces 3.7 million tons of CO2 and more than 50,000 tons/year of the pollutants listed (Miller and Van Atten, 2004).

Bamberger and Oswald are the first peer-reviewed study to link human and animal health with NGD. Their study is supporting evidence of the need for further scientific studies addressing the potential health impacts caused by NGD practices. The authors interviewed 24 case study participants who are animal owners and live near gas drilling development around the country. Although their study is not an epidemiologic analysis, nor is it a study that identifies specific chemical exposures related to NGD, it provides evidence that there are clear health risks present in natural gas development. Their study illustrates the potential impacts on animals by reporting on numerous cases of sudden death of cows, dogs, poultry, birds, goats, amphibians and fish. Their study also indicates that there are many common health problems reported in humans, such as upper respiratory, dermatological, neurological, and gastrointestinal health impacts. One of the major concerns that resulted from this research is that of food safety. Many of these animals were not tested before slaughter and may have entered the human food supply. They also highlight the difficulties researchers face conducting careful studies of the links between NGD and health because of the lack of air and water testing and the use of nondisclosure agreements by the industry.

III Data

III.I Natural Gas Well Data

The data used to identify natural gas wells in the Marcellus shale are from the Pennsylvania Department of Environmental Protection (PA DEP). These data contain the latitudes and longitudes of all the wells drilled in the state of Pennsylvania since 2000. These data define whether the well is a horizontal or vertical well and whether it is a Marcellus shale well. Here, the wells used in this analysis are any well that is defined as a Marcellus shale well. The sample includes two drilled in 2006, 16 drilled in 2007, 193 drilled in 2008, 785 drilled in 2009 and 1462 drilled in 2010. Total, this analysis uses 2,459 natural gas wells completed between 2006 and 2010. These data also contain the county, the company that owns the well, waste water reports, violations, farm name and production. For the analysis that follows, the spud date (date when the drilling rig begins drilling the well) is used to define the timing of NGD.[10]

In addition to the existing gas well data, this study also makes use of the permit data on the PA DEP website. This allows for the identification of permits that do not ever become a well. This information is used to define a potential control group for those infants born to residences close to existing gas wells. The assumption being that these residences are a potential counter factual group: those who have the potential to live close to a gas well in the future, but have not yet had a well drilled as of the timing of the data collection.

III.II Birth Data

The main source of health data for this study is Vital Statistics Natality records from Pennsylvania for the years 2003 to 2010. The total sample used for the entire state is 1,069,699 over these 7 years. The sample of those exposed to natural gas development within 2.5 km of the mother's residence is 2,437. These natality records contain detailed information on every birth in the state including health at birth and background information on the mother and father which includes race, education, marital status, as well as, prenatal care and whether the mother smoked during her pregnancy. This study makes use of the mother's exact address (geocoded to latitude and longitude) and focuses on four birth outcomes.[11] Low birth weight (LBW), defined as birth weight less than 2500 grams, is commonly used as a key indicator of infant health, and hence is one of the outcomes examined. Premature birth, defined as gestation length less than 38 weeks, is associated with a greater risk for short and long term complications, including disabilities and impediments in growth and mental development. Another potential measure of health at birth is the 5 minute APGAR score. The physician rates the infant a 0, 1, or 2 on each of 5 dimensions (heart rate, breathing effort, muscle tone, reflex initiability, and

[10] Here, the spud date is used as is. The drilling rig accounts for the majority of air pollution emissions and is running 24/7 during the first month after spud date, so it is assumed that this date defines the beginning of large quantities of traffic and largest air pollution emissions. Water pollution is likely to happen once a well is hydraulically fractured, if the well casing leaks or there is a spill.

[11] Other outcomes that may be of interest, such as fetal/infant mortality and congenital anomalies are very rare events. When restricting the data set to those very close to gas wells or permits, there are insufficient cases in Pennsylvania for there to be a measurable effect for these outcomes.

color), and then sum the scores, giving an Apgar score of 0-10, where 10 is best. This discrete measure is highly correlated (when the score is low) with the need for respiration support at birth (Almond et al., 2005). The final measure reported, small for gestational age (SGA), is defined as 10th percentile of weight distribution for the gestational week of birth and is used to determine the immediate health care needs of the infant and is used increasingly to predict longterm adverse health outcomes and potential exposure to environmental pollution (Callaghan and Dietz, 2010).[12] Please see tables **??** and 1 for summary statistics.

Using this information, the mothers are defined by the distance between their residences and existing gas wells or permits that have not yet been drilled. The infants born to these residences are also linked to the timing of the nearest gas wells, to construct the potential treatment groups.

IV Empirical Strategy

Since air or water pollution are not randomly assigned, studies that attempt to compare health outcomes for populations exposed to differing pollution levels may not adequately control for confounding determinants of health. In the absence of a randomized trial, this paper exploits the variation over time in the introduction of natural gas development in Pennsylvania during 2003-2010. Combining gas well data and vital statistics allows the comparison of infant health outcomes of those living near a gas well and those living in these locales before drilling began. A commonly used distance in the literature is 2 km from the "treatment" of interest.[13] The results reported in this paper define treatment by three different radiuses: 1.5, 2 and 2.5 km from an unconventional natural gas well or permit. There is little scientific information to base a radius of exposure on and so this paper presents multiple potential radiuses to define exposure.

The difference-in-difference (DD) research design allows for the exploitation of the variation of unconventional gas wells across time and place in Pennsylvania to identify,

[12] This paper uses the World Health Organization weight percentiles calculator (WHO, 2011) which follows the calculations recommended by Mikolajczyk et al. (2011).

[13] See papers described in the background section under Pollution and Infant Health.

causally, the impact of natural gas development on infant health outcomes (prematurity, low birth weight, small for gestational age and 5 minute APGAR scores). To test the validity of the use of this estimator and whether the observable characteristics of these mothers are the same across the treatment and control groups, the following model is used for these specification checks:

$$\begin{aligned} Mom_Char_{it} = \beta_0 + \beta_1 Nearby_{it} + \beta_2 AfterNGD_{it} + \\ \beta_3 Nearby_{it} * AfterNGD_{it} + \beta_4 Year_{it} + \beta_5 Month_{it} \\ + \beta_5 County_{it} + \epsilon_{it} \end{aligned} \tag{1}$$

where Mom_Char_{it} are indicators for mother i's education, age group of motherhood, race or ethnicity, received Women, Infants, and Children (WIC), her method of payment for medical care, and whether she smoked during her pregnancy t. $Nearby_{it}$ is an indicator equal to one if the mother resided within X kilometers of a completed gas well or future gas well during the sample (where X = discrete distances 1, 1.5, 2km estimated in separate regressions). This indicator is designed to capture locales that are in close proximity to permits that become gas wells over the observation period, whether before or after the birth. $AfterNGD_{it}$ is an indicator equal to 1 if birth occurred after well completion. $County_{it}$ is designed to capture any unobserved time-invariant characteristics of each county in the sample. $Year_{it}$ and $Month_{it}$ are included to allow for systematic trends over time within each county. The coefficient of interest is β_3, the interaction between $Nearby_{it}$ and $AfterNGD_{it}$ and identifies the difference-in-differences estimator comparing births before and after natural gas development. The standard errors in these models are clustered at the mother's residence county. If maternal characteristics change in some systematic way, then this selection would need to be taken into account when assessing the impacts of NGD on infant health.

The baseline model examines the effects of unconventional natural gas development on the prevalence low birth weight, small for gestational age and premature birth and also looks at the impact on the average APGAR score. This model is very similar to the model presented in equation 1. The baseline model takes the following form:

$$
\begin{aligned}
Prob(Outcome_{it}) = G(&\beta_0 + \beta_1 Nearby_{it} + \beta_2 AfterNGD_{it} + \\
&\beta_3 Nearby_{it} * AfterNGD_{it} + \beta_4 X_{it} + \alpha_j + \delta_t)
\end{aligned} \tag{2}
$$

Where $G(*)$ is OLS or logit; $Outcome_{it}$ is either prematurity, low birth weight, small for gestational age or 5 minute APGAR scores. The vector X_{it} contains mother and child characteristics including indicators for whether the mother is black or Hispanic, four mother education categories (less than high school (left out category), high school, some college, and college or more), mother age categories (19-24, 25-34 and 35+), an indicator for smoking during pregnancy, an indicator for receipt of Women, Infants, and Children (WIC), three health care payment method categories (Medicaid, private insurance, and self-pay), mother's marital status and an indicator for sex of the child. α_j and δ_t are mother's residence county fixed effects and month and year dummies, respectively. The standard errors in these models are clustered at the mother's residence county. Again, the main coefficient of interest is β_3, which can be interpreted as the difference-in-differences estimator of the impact of an unconventional natural gas well completion before birth on infant health outcomes. It measures the change in outcomes after a well completion, relative to before completion, among births to mothers that live within the specified distance of interest. These models are estimated using a linear probability model due to the ease of computation.

The baseline model, equation (2), is estimated using a comparison group that is restricted to those infants born within the specified distance (1.5, 2 or 2.5 km) of a permit or future gas well. For example, the 2.5 km control group is composed of infants whose mother's residence is within 2.5 km of a permit or future drilled well. The 2.5 km treatment group is thus defined as those infants that are born after an unconventional gas well is completed within 2.5 km of the mother's residence. This is the same for the 1.5 km and 2 km treatment and control groups. This identification strategy assumes that infants born within a similar distance to a permit that is a potential future well would face similar ex ante conditions as those born close to a permit that did become a well during the sample. Infants born to mothers who reside close to potential wells are likely to be the most similar comparison group when it comes to family, geological formation and community characteristics.[14] The state chooses which permits to grant and then the gas companies drill wells according to the available permits (and presumably other resources and expectations about potential profitable production). It is presumable that the reasons for not following up a permit with an actual physical well are exogenous to infant health. This provides an arguably valid comparison group and limits the comparison to those locales before gas drilling has taken place in their communities or locales that will likely have gas drilling at some future date. This should account for both observable characteristics, as well as unobservable characteristics, such as economic factors that promote gas drilling in a community and the unobserved geology of the shale underneath these communities.

A series of robustness checks follows using 2.5 km of a gas well as the treatment group of interest. First, as is commonly used in the literature reviewed in section II.I, the model is estimated using a comparison group that is based upon proximity to an existing gas well (estimated separately for 5 km, 10 km and 15 km from an unconventional gas well). This addresses the intensive margin (comparing infants born closer to a well versus a little further from a well). Second, the baseline model sample is restricted to the years 2008-2010, with permits as the comparison group. This is the most intensive drilling time frame in this sample. Third, the model is estimated including interactions of $Nearby_{it}$ and a linear time trend. This investigates the possibility that areas close to permits that become gas wells during the sample are generally evolving in unobservable ways that are different from other areas that are close to permits that do not become a well during the same period. This will control for any time-varying unobservable characteristics in those communities whose permits become drilled wells from 2006-2010. Finally, the baseline model is estimated separately for white mothers and nonsmokers due to these subgroups tending to have different average birth outcomes. Each of these models are estimated using the four outcomes of interest, namely low birth weight, premature birth, small for

[14]Comparing counties with NGD with those counties that do not is not necessarily going to provide a robust comparison. At the county level, there are multiple demographic and geological differences within and across counties that would make this an inappropriate comparison. This is why the analysis here uses permits as the preferred comparison.

gestational age and 5 minute APGAR score.

One potential threat to the identification strategy is migration of mothers into and out of these communities due to NGD activities. There are two potential ways that this could affect the identification. If mothers who are concerned about the increased pollution and industrialization that comes with natural gas development in their community move out, then there is a potential for the results to be affected. It is, however, unclear whether the results would be biased downward or upwards, i.e. whether it is the mothers who are less or more healthy who would be more likely to leave. The other potential migration effect is that those who are working for the gas companies are moving into these communities (these individuals are likely to be male). With few changes in average demographic characteristics of those living near gas wells over time in the sample used, it is unlikely that there is a threat to the research design. However, the models are estimated with demographic controls, time trends (month and year), and county fixed trends to insure that any changes in the population are controlled for.

V Results

Table 2 shows the results of examining the validity of the DD design, predicting the maternal characteristics with the treatment variables. Each coefficient represents an estimate of β_3 from a separate regression. These are estimated separately for the various distances explored: 1.5, 2 and 2.5 km. One maternal characteristic shows statistically significant changes with the introduction of NGD: mother's education. At 2 km of a gas well or permit, the completion of an unconventional gas well before birth results in a reduced prevalence of high school completions and an increased likelihood that the mom has completed college. Similarly, at 2.5 km, there appears to be less mothers with some college and more mothers with college degrees. There are no other characteristics that have statistically detectable differences after natural gas development compared with before. Increased college completions amongst mothers would suggest improvements in infant health in these communities.

Table 3 shows the estimates using permits as the comparison group. Each column represents a separate regression that estimates equation (2) and is an estimate of β_3, the difference-in-difference estimator. The first column for each outcome of interest shows a model that controls only for month and year of birth and county of mother's residence. The second column for each outcome adds maternal characteristics as in equation (2). Given the assumption that the research design is valid, adding controls for observable characteristics of the mother should only reduce the sampling variance while leaving the coefficient estimates qualitatively unchanged. The results in the second column for each outcome are consistent with the research design since adding these maternal characteristics does not change the magnitude of the coefficients by much, and are most consistent at 2.5 km of a gas well or permit, which is the distance most reported throughout.[15]

The estimates in Table 3 demonstrate a statistically significant increase in the prevalence of LBW born to residences that are located 1.5, 2 and 2.5 km from an unconventional natural gas well, when compared to those infants born the same distances from permits or future wells. These estimates suggest that NGD within 2.5 km of a mother's residence increased LBW by 1.75 percentage points, or a 25 percent increase in the overall prevalence of LBW in these communities (base is 7.1% LBW; 0.0175/0.071=25). This suggests that of the 2,437 births that are observed within 2.5 km of an unconventional natural gas well, 43 additional were born LBW after unconventional natural gas development in this sample. At 1.5 and 2 km from a gas well, the incidence of LBW increased by 1.7 and 1.5 percentage points, respectively. This indicates that LBW prevalence increased by between 21 and 26 percent, depending on the proximity of mother's residence to NGD. As the distances increase from a nearby gas well, the estimates become statistically indistinguishable from zero at 4 km.[16] Similarly, APGAR scores are reduced at close proximities (1.5 and 2.5 km) indicating an average reduction in physician observed health at birth. Small for gestational age is not statistically detectable until 2.5 km and shows a 1.7 percentage point increase in SGA prevalence when the mother's residence is within 2.5 km of an unconventional natural gas well completed prior to birth. This indicates that overall SGA prevalence increased by 17 percent in these communities (on a base of 9.8

[15] The slight differences here are likely driven by the different samples due to missing mother characteristics.

[16] Estimates not shown and are available by request from author.

percent). Premature birth prevalence is not statistically significant from zero, except at 2 km, where there is a 1 percentage point reduction in premature birth or, using a similar calculation, an overall reduction in the prevalence of prematurity of 11 percent (on a base of 9 percent).[17]

These results in Table 3 are corroborated by the similarity in observable characteristics (see Table 1) between those mothers who live close (1.5, 2 or 2.5 km) to a gas well and those who live a similar distance from a permit that never became a well. The only differences are that those mothers with infants born after NGD are less likely to be over the age of 35, less likely to be black and more likely to go to college, on average. These differences are not likely to increase the LBW prevalence amongst infants born to households close to gas wells. When looking at the sample means, those born after NGD may be more likely to use WIC and Medicaid. However, when controlling for county time trends, Table 2 suggests no changes in these economic variables after natural gas development.

To confirm the validity of these results, this paper provides multiple robustness checks. Table 4 shows estimates at the intensive margins using 15 km, 10 km and 5 km as comparison groups.[18] These results, for the 15 km comparison group, suggest an increased prevalence of LBW by 0.9 percentage points and a reduced APGAR score for infants born less than 2.5 km of an unconventional natural gas well. These are smaller in magnitude when compared to the baseline results reported in Table 3. For APGAR scores, the coefficient remains negative, and statistically significant for comparison groups of 10 and 5 km. There are no detectable impacts on prematurity or SGA at any of these comparison distances. At a 15 km intensive margin, which may be plausible depending on the level of exposure over distance of which is currently unknown, the baseline results remain consistent for LBW and APGAR scores, at all three treatment distances (1.5, 2 and 2.5 km;

[17]A large increase in income to a community that is otherwise rural and relatively poor may improve health outcomes since these families may have the income to get better health care, nutrition, water, etc. This may lead to understating the negative health impacts at the closest proximities to wells. At the closest proximities, there appears to be some mixed results that may suggest some plausibility to this argument. Premature birth may be showing an improvement in health due to increased income and an improved economic environment in these communities, but this improvement in economic status does not appear to cancel out the negative health outcomes demonstrated by other measures of health at birth. Despite a reduction in premature birth at 2 km, the prevalence of LBW increases in similar magnitude.

[18]Tables 8 and 7 in the appendix show the intensive margins for 1.5 and 2 km.

see appendix).

The additional robustness checks are presented in Table 5. For all four panels, the results remain consistent for LBW but do not show any statistically detectable impacts for the other three measures of health at birth. The first panel shows the effect of restricting the sample to infants born in 2008 to 2010 and reduces the sample to the years when most of the unconventional natural gas development has taken place in the Marcellus Shale in Pennsylvania. The sample here is about 36 percent of the original sample that includes 2003-2010 and the standard errors increase in all four columns compared with the baseline results, which may explain the lack of statistical power for the other three measures. Only the impact on LBW remains statistically detectable and suggests a 2.6 percentage point increase in LBW in these three years. This translates to at 37 percent increase in the overall prevalence of LBW. This is substantially larger than the findings in Table 3 and suggests that the baseline findings are not driven by the additional years in the comparison group. Panel 2 reports the results from adding interactions of a linear time trend and $Nearby_{it}$ to equation (2) and again suggests a larger impact on LBW within the radius of 2.5 km compared to Table 3. Adding these time trends capture any differences between the evolution of areas that are close to permits that become wells and the other areas with underutilized permits (e.g. different geology, well productivity, availability of resources, etc.).

The last two panels of Table 5 highlight two important subgroups. For white mothers and nonsmokers, the prevalence of LBW increases by 1.95 and 1.59 percentage points, respectively. These results indicate that the impacts estimated in Table 3 are not driven by African American mothers or mothers who smoked while pregnant, which are two subgroups more likely to have low birth weight babies on average. The samples of African Americans and mothers who smoked while pregnant are substantially smaller in size and suggest no impacts across all 4 measures at 2.5 km.[19]

The findings above are large but not implausible given the estimates in the literature of air pollution and infant health. For example, Currie and Walker (2011) estimate that reductions in air pollution from E-ZPass result in reductions of LBW between 8.5-11.3

[19]Results not shown and available upon request from author.

percent and Currie et al. (2009) find that a one unit change in the mean level of carbon monoxide increases the risk of LBW by 8 percent. This study presents estimates that suggest that across specifications discussed above NGD increases the overall risk of LBW by 25 percent when using mother's residences within a 2.5 km radius of an unconventional gas well, before and after drilling took place. The direction of the estimated impacts are robust across multiple comparison groups and allows the reader the opportunity to ask different research questions.[20]

VI Conclusions

This paper provides the first estimates of the effects of unconventional natural gas development on infant health. There are no other known studies, to date, linking NGD directly to human health at this scale. These results suggest that natural gas wells close to pregnant mothers' residences increased LBW by 25%, increased small for gestational age by 17% and reduced 5 minute APGAR scores, when compared to pregnant mothers' residences that are close to a future well (permit). For comparison, Currie et al. (2009) find that smoking in utero increases LBW by 0.18 percentage points on a baseline of 0.089 or a 2% increase in the overall prevalence of LBW in NJ during their study period. These impacts are large compared to mothers smoking, but not implausible given the estimates found in the literature for air pollution impacts on LBW. The strength of this approach is in exploiting a natural experiment that controls for unobservable characteristics. These results are robust across a variety of specifications, which provides evidence of the credibility of the current research design.

These results suggest that policies that intend to prevent pollution exposure stemming from unconventional natural gas development should increase the regulated/allowable distance between drilling activity and nearby residences. This paper provides evidence that exposure within at least 1.5 miles is very detrimental to fetal development. Some specifications not shown suggest that exposure is still detectable within 3 or more miles from the residences of pregnant women (results are available upon request from author). With

[20]For example: 1)what is the impact of NGD compared to similar geological locations that will likely have NGD in the future? and 2) what is the intensive margin of the impact?

unconventional natural gas development expanding throughout 31 states, there is likely to be many exposed babies resulting in a nationwide increase in LBW. A recent report from the Institute of Medicine estimates that the cost to society of low birth weight and premature birth is $51,600 per infant for the first year of health care costs (in 2005 dollars, Behrman and Butler).[21] Due to unconventional natural gas development occurring only recently in Pennsylvania, the number of infants observed close to existing wells before birth is quite small, or just under 2,500 babies. This translates to a cost of $2.2 million and accounts mostly for infants born after gas development in 2010. Even if only the same number of infants were exposed in 2011, that is still a cost of $4.4 million in infant health costs associated with 2 years of natural gas development. This is likely to be a lower bound given that 2,618 additional wells were drilled in 2011 (DEP, 2010). Using the sample of permits as an example, there were 21,646 infants born within 2.5 km of a permit or existing well. The estimates in this paper suggest that, if all of these permits were drilled prior to birth, we would expect to see 379 additional LBW infants, an increase that could be valued at $19.6 million. Unfortunately, we do not have any studies in other states to determine the number of infants exposed within these proximities to be able to determine the nation-wide costs associated with the infant health impacts of unconventional natural gas development.

Investigating the health impacts of unconventional natural gas development is an ambitious and complicated project. The present analyses take the first steps towards estimating impacts on health at birth. Since this paper only investigates one of the potential health effects, namely infant health at birth, the total increased health costs due to unconventional natural gas development are likely to be much greater. These results indicate that more research on unconventional natural gas development and health impacts on all members of our society is warranted.

[21] Estimates available for costs of LBW are lumped with premature birth.

References

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

R. Alvarez and E.D. Fund. Emissions from natural gas production in the barnett shale area and opportunities for cost-effective improvements. 2009.

M. Bamberger and R.E. Oswald. Impacts of gas drilling on human and animal health. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, pages 51–77.

A. Bar-Ilan, R. Friesen, J. Grant, A. Pollack, D. Henderer, D. Pring, K. Sgamma, and T. Moore. A comprehensive oil and gas emissions inventory for the denver-julesburg basin in colorado, 2008.

Richard E Behrman and Adrienne Stith Butler. Preterm birth: Causes, consequences, and prevention.

E. Brainerd and N. Menon. Seasonal effects of water quality on infant and child health in india. 2011.

W.M. Callaghan and P.M. Dietz. Differences in birth weight for gestational age distributions according to the measures used to assign gestational age. *American journal of epidemiology*, 171(7):826–836, 2010.

K.Y. Chay and M. Greenstone. Air quality, infant mortality, and the clean air act of 1970. Technical report, National Bureau of Economic Research, 2003.

COGCC. Statement of basis, specific statutory authority, and purpose: New rules and amendments to current rules of the colorado oil and gas conservation commission, 2 ccr 404-1. *Colorado Oil and Gas Conservation Commission*, 2009.

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

ALL Consulting. Ny dec sgeis information requests. 2010.

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

J. Currie and M. Neidell. Air pollution and infant health: What can we learn from california's recent experience? *Quaterly journal of economics*, 120(3):1003–1030, 2005.

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

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

J. Currie, M. Neidell, and J.F. Schmieder. Air pollution and infant health: Lessons from new jersey. *Journal of health economics*, 28(3):688–703, 2009.

J. Currie, M. Greenstone, and E. Morettia. Superfund cleanups and infant health. *The American Economic Review*, 101(3):435–441, 2011.

PA DEP. Marcellus permits issued wells drilled, 2010. URL `http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2010PermitDrilledmaps.htm`.

Inc. Eastern Research Group. Drilling rig emission inventory for the state of texas, 2009.

Energy and Commerce Committee. Chemicals used in hydraulic fracturing. *US House Of Representatives*, 2011.

Geology.com. Marcellus shale- appalachian basin natural gas play, 2012. URL `http://www.geology.com/articles/marcellus-shale.shtml`.

S.V. Glinianaia, J. Rankin, R. Bell, T. Pless-Mulloli, and D. Howel. Particulate air pollution and fetal health: a systematic review of the epidemiologic evidence. *Epidemiology*, 15(1):36, 2004a.

M. Greenstone and R. Hanna. Environmental regulations, air and water pollution, and infant mortality in india. Technical report, National Bureau of Economic Research, 2011.

IEA. Golden rules for a golden age of natural gas. 2012.

Matt Kelso. Marcellus shale production decline over time in pennsylvania, 2011. URL `http://www.fractracker.org/?p=940`.

C.R. Knittel, D.L. Miller, and N.J. Sanders. Caution, drivers! children present: Traffic, pollution, and infant health. 2011.

ALL Consulting LLC. Modern shale gas development in the united states: A primer, 2009.

Abraham Lustgarten. Is new york's marcellus shale too hot to handle?, 2009. URL `http://www.propublica.org/article/is-the-marcellus-shale-too-hot-to-handle-1109`.

D.R. Mattison, S. Wilson, C. Coussens, and ed. Gilbert, D. *The Role of Environmental Hazards in Premature Birth: Workshop Summary*. National Academies Press, 2003.

L.M. McKenzie, R.Z. Witter, L.S. Newman, and J.L. Adgate. Human health risk assessment of air emissions from development of unconventional natural gas resources. *Science of The Total Environment*, 2012.

R.T. Mikolajczyk, J. Zhang, A.P. Betran, J.P. Souza, R. Mori, A.M. Gülmezoglu, and M. Merialdi. A global reference for fetal-weight and birthweight percentiles. *The Lancet*, 377(9780):1855–1861, 2011.

P.J. Miller and C. Van Atten. *North American power plant air emissions*. Comission for Environmental Cooperation of North America, 2004.

LP Sage Environmental Consulting. City of fort worth natural gas air quality study. 2011.

M.T. Salam, J. Millstein, Y.F. Li, F.W. Lurmann, H.G. Margolis, and F.D. Gilliland. Birth outcomes and prenatal exposure to ozone, carbon monoxide, and particulate matter: results from the childrens health study. *Environmental health perspectives*, 113(11): 1638, 2005.

J. Schwartz. Air pollution and childrens health. *Pediatrics*, 113(4):1037, 2004.

STRONGER. Pennsylvania hydraulic fracturing review. 2010.

H. Vidas and B. Hugman. Availability, economics, and production potential of north american unconventional natural gas supplies. *Fairfax, Va.: The INGAA Foundation*, 2008.

WHO. Who weight percentages calculator, 2011. URL http://www.who.int/entity/reproductivehealth/topics/best_practices/weight_percentiles_calc

B. Zielinska, E. Fujita, and D. Campbell. Monitoring of emissions from barnett shale natural gas production facilities for population exposure assessment., 2010.

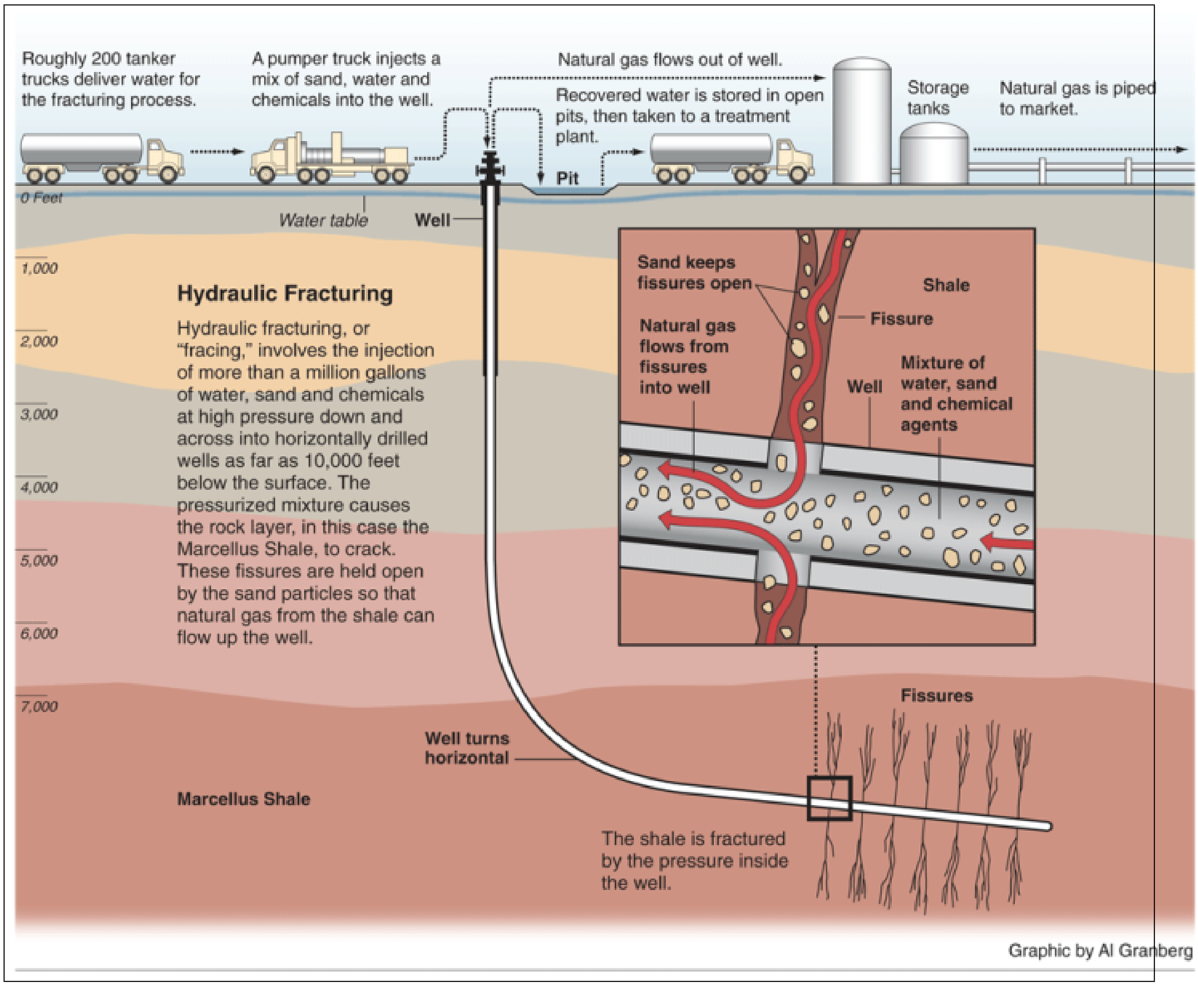

Figure 1: Graphical Representation of NGD Process

Table 1: Summary Statistics (<2.5 km from gas well or permit)

	Sample means		T-ratio	Rest of PA
	Before NGD	After NGD		
<2.5 km from a well or permit				
Characteristics of Birth				
Low birth weight	0.071	0.08	1.59	0.087
Premature	0.09	0.09	0.02	0.10
APGAR 5 min	8.88	8.86	0.07	8.79
Small for Gestational Age	0.106	0.115	1.38	0.116
Female Child	0.488	0.494	0.5	0.488
Mother's Demographic Characteristics				
High school	0.299	0.288	1.12	0.269
Some college	0.302	0.293	0.91	0.260
College or more	0.281	0.300	2.00*	0.302
Teen Mom	0.047	0.48	0.37	0.056
Mom age (19-24)	0.273	0.270	0.38	0.262
Mom age (20-34)	0.541	0.561	1.9	0.529
Mom age (35+)	0.138	0.120	2.47*	0.153
Mom Black	0.024	0.025	0.13	0.157
Mom Hispanic	0.011	0.010	0.32	0.092
Smoked during pregnancy	0.301	0.300	0.18	0.225
Mom Married	0.636	0.630	0.59	0.578
WIC recipient	0.404	0.428	2.27*	0.384
Medicaid	0.33	0.373	4.25***	0.270
Private Insurance	0.575	0.554	2.04*	0.579
N	19858	2437		1122459

* p<0.05, ** p<0.01, *** p<0.001

Table 2: Testing Validity of DD Research Design: Regressions of Maternal Characteristics

	High School (1)	Some College (2)	College (3)	Smoked (4)	Black (5)	Hispanic (6)	WIC (7)	Medicaid (8)
Panel 1: All Observations within 1.5km of well or permit								
<1.5 km gas well * NGD before birth	-0.0104	0.0168	-0.0143	-0.0223	0.00121	0.000829	-0.0093	-0.0117
	(0.0222)	(0.0136)	(0.0166)	(0.0266)	(0.00207)	(0.00448)	(0.0299)	(0.0367)
R2	0.033	0.015	0.066	0.032	0.03	0.009	0.077	0.106
Number Observations	8208	8208	8208	8208	8208	8208	8208	8208
Panel 2: All Observations within 2 km of a Gas Well or Permit								
<2 km gas well * NGD before birth	-0.0251*	-0.0142	0.0433*	-0.00376	0.00224	-0.000896	-0.0254	-0.028
	(0.0132)	(0.0143)	(0.0223)	(0.0242)	(0.00449)	(0.00438)	(0.0269)	(0.0277)
R2	0.026	0.009	0.050	0.026	0.017	0.006	0.064	0.092
Number Observations	14131	14131	14131	14131	14131	14131	14131	14131
Panel 3: All Observations within 2.5 km of a Gas Well or Permit								
<2.5 km gas well * NGD before birth	-0.0201	-0.0283***	0.0630***	0.00292	0.00391	-0.00253	-0.00812	-0.0186
	(0.0129)	(0.00647)	(0.0162)	(0.0192)	(0.00319)	(0.00324)	(0.0252)	(0.0287)
R2	0.024	0.008	0.042	0.022	0.013	0.004	0.056	0.073
Number Observations	21646	21646	21646	21646	21646	21646	21646	21646

Notes: Each coefficient is from a different regression. All regressions include controls for being within distance listed of an existing gas well, indicators for month and year of birth, county indicators and an indicator for NGD before birth. Standard errors are in parentheses and clustered at mother's residence county.

* p<0.05, ** p<0.01, *** p<0.001

Table 3: Regressions of Birth Outcomes on Introduction of Natural Gas Development (Gas Permits as Comparison Group)

	LBW (1)	LBW (2)	Premature (3)	Premature (4)	APGAR (5)	APGAR (6)	SGA (7)	SGA (8)
Panel 1: All Observations within 1.5km of well or permit								
<1.5km gas well * NGD before birth	0.0102	0.0166**	0.0018	0.00424	-0.0805*	-0.0880**	-0.0113	-0.0074
	(0.00900)	(0.00775)	(0.0104)	(0.0118)	(0.0441)	(0.0410)	(0.0135)	(0.0131)
R^2	0.009	0.02	0.01	0.017	0.017	0.021	0.011	0.043
Number of Observations	8208	7361	8208	7361	8175	7330	8170	7327
Panel 2: All Observations within 2 km of well or permit								
<2 km gas well * NGD before birth	0.0134**	0.0150**	-0.0110**	-0.0105**	-0.0075	-0.0118	0.0028	0.00225
	(0.00595)	(0.00593)	(0.00473)	(0.00446)	(0.0266)	(0.0263)	(0.00906)	(0.0107)
R^2	0.006	0.018	0.007	0.013	0.013	0.016	0.006	0.038
Number of Observations	14131	12728	14131	12728	14080	12681	14054	12657
Panel 3: All Observations within 2.5km of well or permit								
<2.5km gas well * NGD before birth	0.0172**	0.0175**	-0.0008	0.0000	-0.0324	-0.0389*	0.0182**	0.0167**
	(0.00657)	(0.00682)	(0.00666)	(0.00706)	(0.0211)	(0.0220)	(0.00768)	(0.00815)
R^2	0.006	0.017	0.005	0.009	0.011	0.015	0.005	0.037
Number of Observations	21646	19528	21646	19528	21569	19458	21524	19412
Maternal Characteristics	no	yes	no	yes	no	yes	no	yes

Notes: Each coefficient is from a different regression. All regressions include indicators for month and year of birth, residence county indicators, an indicator for NGD before birth (within 15km of residence), an indicator for specified distance from a well or future well/permit and the interaction of interest reported above. Maternal characteristics include mother black, mother Hispanic, mother education (hs, some college, college), mother age (19-24,25-34, 35+), female child, WIC, smoking during pregnancy, marital status and payment type (private insurance, medicaid, self-pay, other). Standard errors are in parentheses and clustered at the mother's residence county.

* p<0.05, ** p<0.01, *** p<0.001

Table 4: Regressions of Birth Outcomes on the Introduction of NGD (Intensive Margin at 2.5 km of gas well)

	LBW	Prematurity	APGAR	SGA
	(1)	(2)	(3)	(4)
Panel 1: All Observations within 15 km				
<2.5km gas well * NGD before birth	0.00913*	-0.00113	-0.0523***	0.00711
	(0.00470)	(0.00407)	(0.0163)	(0.00584)
R^2	0.018	0.008	0.022	0.034
N	166202	166202	165563	164996
Panel 2: All Observations within 10 km				
<2.5km gas well * NGD before birth	0.00762	-0.00328	-0.0441***	0.00620
	(0.00500)	(0.00440)	(0.0152)	(0.00581)
R^2	0.016	0.007	0.018	0.033
N	97459	97459	97099	96765
Panel 3: All observations within 5km				
<2.5km gas well * NGD before birth	0.0074	-0.00601	-0.0536***	0.000940
	(0.00484)	(0.00616)	(0.0124)	(0.00576)
R^2	0.018	0.008	0.015	0.036
N	40032	40032	39877	39774

Notes: Each coefficient is from a different regression. All regressions include indicators for month and year of birth, residence county indicators, an indicator for NGD before birth (within 15km of residence), an indicator for specified distance from a well or future well/permit and the interaction of interest reported above. Maternal characteristics include mother black, mother Hispanic, mother education (hs, some college, college), mother age (19-24,25-34, 35+), female child, WIC, smoking during pregnancy, marital status and payment type (private insurance, medicaid, self-pay, other). Standard errors are in parentheses and clustered at the mother's residence county.

* p<0.05, ** p<0.01, *** p<0.001

Table 5: Robustness Checks, Birth Outcomes on the Introduction of NGD

	LBW (1)	Prematurity (2)	APGAR (3)	SGA (4)
Panel 1: All observations 2008-2010				
<2.5km gas well * NGD before birth	0.0256	0.0014	-0.0269	0.0148
	(0.0150)*	(0.0124)	(0.0641)	(0.0149)
R^2	0.022	0.013	0.029	0.050
Number of Observations	7107	7107	7087	7082
Panel 2: Add time trends for areas post NGD				
<2.5km gas well * NGD before birth	0.0274	0.0140	-0.0369	0.0064
	(0.008)**	(0.008)	(0.032)	(0.014)
R^2	0.017	0.010	0.015	0.037
Number of Observations	19528	19528	19458	19412
Panel 3: White Mothers Only				
<2.5km gas well * NGD before birth	0.0195	0.0010	-0.0405	0.0183
	(0.007)**	(0.007)	(0.020)	(0.009)
R^2	0.016	0.009	0.015	0.037
Number of Observations	18878	18878	18812	18763
Panel 4: Nonsmokers Only				
<2.5km gas well * NGD before birth	0.0159	-0.0010	-0.0272	0.0191
	(0.007)*	(0.008)	(0.024)	(0.011)
R^2	0.010	0.010	0.018	0.016
Number of Observations	13463	13463	13463	13463

Notes: Each coefficient is from a different regression. All regressions include indicators for month and year of birth, residence county indicators, an indicator for NGD before birth (within 15km of residence), an indicator for specified distance from a well or future well/permit and the interaction of interest reported above. Maternal characteristics include mother black, mother Hispanic, mother education (hs, some college, college), mother age (19-24,25-34, 35+), female child, WIC, smoking during pregnancy, marital status and payment type (private insurance, medicaid, self-pay, other). Standard errors are in parentheses and clustered at the mother's residence county.

* p<0.05, ** p<0.01, *** p<0.001

VII Appendix

Table 6: Summary Statistics (<1.5 and <2 km from gas well or permit)

	Sample means		T-ratio	Rest of PA
	Before NGD	After NGD		
Panel 1: <1.5 km from a well or permit				
Outcomes				
Low birth weight	0.071	0.089	1.92	0.087
Premature	0.091	0.089	0.23	0.100
APGAR Score (5 minute)	8.87	8.86	0.43	8.79
Small for Gestational Age	0.101	0.109	0.77	0.116
Controls				
Female child	0.484	0.473	0.62	0.488
Teen Mom	0.044	0.058	1.89	0.056
Mother Age	27.99	27.12	4.10***	27.88
High school	0.297	0.292	0.28	0.269
Some college	0.298	0.307	0.56	0.260
College or more	0.295	0.261	2.05*	0.302
Mom Black	0.018	0.024	1.18	0.155
Mom Hispanic	0.008	0.013	1.39	0.091
Smoked during pregnancy	0.292	0.296	0.2	0.226
Mom Married	0.379	0.423	2.52*	0.578
WIC recipient	0.3	0.384	5.05***	0.384
Medicaid	0.653	0.615	2.20*	0.27
Private Insurance	0.591	0.546	2.52*	0.578
Number of Observations	7600	846		1136308
Panel 2: <2 km from a well or permit				
Outcomes				
Low birth weight	0.072	0.08	1.24	0.087
Premature	0.091	0.091	0.07	0.100
APGAR Score (5 minute)	8.875	8.894	0.99	8.79
Small for Gestational Age	0.104	0.106	0.21	0.116
Controls				
Female child	0.484	0.49	0.42	0.488
Teen Mom	0.043	0.051	1.35	0.056
Mother Age	27.95	27.33	3.96***	27.88
High school	0.296	0.292	0.32	0.269
Some college	0.300	0.303	0.23	0.260
College or more	0.298	0.280	1.38	0.302
Mom Black	0.019	0.021	0.52	0.156
Mom Hispanic	0.009	0.012	0.96	0.091
Smoked during pregnancy	0.297	0.307	0.75	0.226
Mom Married	0.644	0.631	0.99	0.578
WIC recipient	0.385	0.423	2.88**	0.384
Medicaid	0.306	0.378	5.70***	0.270
Private Insurance	0.585	0.556	2.14*	0.578
Number of Observations	13027	1533		1130194

* p<0.05, ** p<0.01, *** p<0.001

Table 7: Regressions of Birth Outcomes on the Introduction of NGD (Intensive Margin at 2 km of gas well)

	LBW	Prematurity	APGAR	SGA
	(1)	(2)	(3)	(4)
Panel 1: All Observations within 15 km				
<2km gas well * NGD before birth	0.00612*	-0.00627	-0.0360*	-0.00673
	(0.00340)	(0.00565)	(0.0199)	(0.00862)
R^2	0.018	0.018	0.022	0.034
N	166202	166202	165563	164996
Panel 2: All Observations within 10 km				
<2km gas well * NGD before birth	0.00441	-0.00853	-0.0268	-0.00823
	(0.00363)	(0.00596)	(0.0186)	(0.00874)
R^2	0.016	0.016	0.018	0.033
N	97459	97459	97099	96765
Panel 3: All observations within 5km				
<2km gas well * NGD before birth	0.00325	-0.0115	-0.0300*	-0.0150
	(0.00375)	(0.00717)	(0.0174)	(0.00936)
R^2	0.018	0.018	0.015	0.036
N	40032	40032	39877	39774

Notes: Each coefficient is from a different regression. All regressions include indicators for month and year of birth, residence county indicators, an indicator for NGD before birth (within 15km of residence), an indicator for specified distance from a well or future well/permit and the interaction of interest reported above. Maternal characteristics include mother black, mother Hispanic, mother education (hs, some college, college), mother age (19-24,25-34, 35+), female child, WIC, smoking during pregnancy, marital status and payment type (private insurance, medicaid, self-pay, other). Standard errors are in parentheses and clustered at the mother's residence county.

* p<0.05, ** p<0.01, *** p<0.001

Table 8: Regressions of Birth Outcomes on the Introduction of NGD (Intensive Margin at 1.5 km of gas well)

	LBW (1)	Prematurity (2)	APGAR (3)	SGA (4)
Panel 1: All Observations within 15 km				
<1.5km gas well * NGD before birth	0.0117**	-0.00712	-0.0697*	-0.00612
	(0.00527)	(0.0107)	(0.0406)	(0.0114)
R^2	0.018	0.018	0.022	0.034
N	166202	166202	165563	164996
Panel 2: All Observations within 10 km				
<1.5km gas well * NGD before birth	0.00989*	-0.00924	-0.0602	-0.00767
	(0.00576)	(0.0106)	(0.0397)	(0.0117)
R^2	0.016	0.016	0.018	0.033
N	97459	97459	97099	96765
Panel 3: All observations within 5km				
<1.5km gas well * NGD before birth	0.00892	-0.0117	-0.0633	-0.0132
	(0.00549)	(0.0117)	(0.0390)	(0.0116)
R^2	0.018	0.018	0.015	0.036
N	40032	40032	39877	39774

Notes: Each coefficient is from a different regression. All regressions include indicators for month and year of birth, residence county indicators, an indicator for NGD before birth (within 15km of residence), an indicator for specified distance from a well or future well/permit and the interaction of interest reported above. Maternal characteristics include mother black, mother Hispanic, mother education (hs, some college, college), mother age (19-24,25-34, 35+), female child, WIC, smoking during pregnancy, marital status and payment type (private insurance, medicaid, self-pay, other). Standard errors are in parentheses and clustered at the mother's residence county.

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

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