Natural Gas Operations and Infant Health

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April 2012

Abstract

Over the last decade, intensive natural gas drilling 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 operations with human health directly on an aggregate scale. This research exploits the natural experiment of the gradual introduction of natural gas wells to identify the impacts of resulting air and water pollution on infant health. The immediate outcomes of interest are infant health measures (low birth weight, premature birth and 5 minute APGAR scores). This study examines singleton births to mothers residing close to a natural gas well from 2003-2010 in Pennsylvania. The difference in differences approach (DD) compares birth outcomes before and after a gas well was completed for mothers who live close to a gas well. The results suggest that exposure to NGO before birth increases the prevalence of low birth weight and reduces 5 minute APGAR scores, while no impact on premature birth is detected.

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1 Introduction

New technologies have made it economically feasible to extract natural gas from various geological formations in the United States and elsewhere. Natural gas operations (NGO) are exempted from the Safe Drinking Water Act, Clean Air Act, and Clean Water Act regulations, as well as others. Operations now exist in 31 states and are currently unregulated in most of those states. Most recently, NGO has been used extensively in Pennsylvania in the Marcellus Shale that spans West Virginia, Pennsylvania and New York. NGO 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 negative effects associated with NGO. Serious environmental and health concerns have emerged regarding NGO that may outweigh the perceived benefits of the technique. To shed light on the matter, this research investigates the causal relationship between NGO and infant health.

The causal relationship between natural gas operations 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 future health problems and lower educational attainment (see Currie (2009) for a summary of this research). 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, NGO 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 NGO. So, although NGO is not randomly assigned to locales, counties or states, it does offer an interesting natural experiment for investigating the effects of

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

pollution on health. Fourth, most of the literature links fetal health impacts to air pollution, but NGO 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.

2 Background

2.1 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 effects and compare siblings before and after the adoption of E-ZPass. Knittel et al. (2011)

[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).

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 accross 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 NGO 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 NGO 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.

2.2 Background on Natural Gas Operations

In Pennsylvania, natural gas operations (NGO) includes 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 operations, this research focuses on the entire process of NGO. 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 operations 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 facturing. 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 (ALL Consulting, 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 NGO 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).

It is likely that gas companies choose the leases they take to the state based upon

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

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.

2.3 Natural Gas Operations As Potential Pollution Sources

Preliminary evidence indicates that NGO 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 containing 750 chemicals and other components. Of these 2,500 products, 650 contained

[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.

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 NGO fluid and is brought to the surface through the NGO 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 flowback 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 NGO have 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 NGO may be causing air pollution.

2.4 Related Literature on Health and Natural Gas Operations

Most of the studies to date that address potential health impacts of NGO 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 NGO 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 NGO. Their study is supporting evidence of the need for further scientific studies addressing the potential health impacts caused by NGO practices. The authors introviewed 24 case study participants who are animal owners and live near gas drilling operations around the country. Although their study is not an epidemiologic analysis, nor is it a study that identifies specific chemical exposures related to NGO, it provides evidence that there are clear health risks present in natural gas operations. 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 NGO and health because of the lack of air and water testing and the use of nondisclosure agreements by the industry.

3 Data

3.1 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 NGO.[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 counterfactual 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.

3.2 Birth Data

The main source of health data for this study are 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 operations within 2.5 km and 3.5 km of the mother's residence are 2,437 and 4,730, respectively. 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 three birth outcomes: prematurity (defined as an estimated gestation length less than 38 weeks), low birth weight (defined as birth weights below 2,500 grams) and 5 minute APGAR scores (an index of 5 dimensions of health at birth: heart rate, breathing effort, muscle tone, reflex initiability, and color).[11] Please see tables 1 and 2 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

[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 measureable effect for these outcomes.

to these residences are also linked to the timing of the nearest gas wells, to construct the potential treatment groups.

4 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 operations 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 further away. A commonly used distance in the literature is 2km from the "treatment" of interest.[12]

The difference-in-difference (DD) research design allows for the exploitation of the variation of injection wells across time and place in Pennsylvania to identify, causally, the impact of NGO on infant health outcomes (prematurity, low birth weight and 5 minute APGAR scores). The estimated equation takes the following form:

$$\begin{aligned} Prob(Outcome_{it}) = G(&\beta_0 + \beta_1 Nearby_{it} + \beta_2 AfterNGO_{it} + \\ &\beta_3 Nearby_{it} * AfterNGO_{it} + \beta_4 X_{it} + \alpha_j + \delta_t) \end{aligned} \tag{1}$$

where $G(*)$ is OLS or logit; $Outcome_{it}$ is either prematurity, low birth weight or 5 minute APGAR scores; $Nearby_{it}$ is an indicator equal to one if the mother resided within X kilometers of a completed gas well (or future gas well/permit) during the sample (where X = discrete distances 1, 1.5, 2,...10.5km); $AfterNGO_{it}$ is an indicator equal to 1 if birth occurred after well completion within 15km of the mother's residence. 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

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

Women, Infants, and Children (WIC); and an indicator for sex of the child. α_j and δ_t are county fixed effects and month and year dummies, respectively.

The main coefficient of interest is β_3, which can be interpreted as the difference-in-differences estimator of the impact of a gas well completion 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.

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, equation (1) is estimated with mother characteristics as dependent variables. The coefficient of interest is the same as above, the interaction between $Nearby_{it}$ and $AfterNGO_{it}$. If maternal characteristics change in some systematic way, then this selection would need to be taken into account when assessing the impacts of NGO on infant health.

First, the baseline model is estimated using the entire state as the comparison group. Due to the lack of scientific studies that would help determine the distances that matter for exposure to a natural gas well in the Marcellus Shale, results are presented for 1km to 10km (in 0.5km increments) from the mother's residence. Subsequent models primarily define treatment as residences within 2.5 and 3.5km from a gas well. The second specification estimates equation (1) but restricts the comparison group based upon proximity to a gas well (5km, 10km and 15km). This addresses the intensive margin (comparing infants born closer to a well versus a little further from a well). Third, assuming 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, the comparison group is restricted to infants born within 2.5 and 3.5km of a permit. Each of these models are then estimated using the three outcomes of interest, namely low birth weight, premature birth and 5 minute APGAR score.

One potential threat to the identification strategy is migration of mothers into and out of these communities due to NGO 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 NGO in their community move out, then there is a potential for the results to be affected. It is however unclear whether the result would be biased downward or upwards, i.e. whether it is the mother's 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, 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.

5 Results

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, the sample is very small and so it is not statistically feasible to test this potential bias.

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 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 results are hence presented across all these outcomes.

Table 3 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 at 2.5 and 3.5km from a gas well. Two maternal characteristics show significant changes with the introduction of NGO: a reduction in mother's having some college and an increase in mothers completing college. Either more educated mothers are moving into these communities after NGO or the same mothers are switching status over the 7 years of observation from some college to college. Neither should be of major concern for the DD estimator. At 3.5km the results are very similar (although the reduction for some college is no longer significant) and there is a statistically significant reduced prevalence of WIC use.

Table 4 shows estimates of the probability of LBW and prematurity for infants born within small distances of a previously completed natural gas well compared to those in the rest of the state. These results suggest that NGO within 3km of a mother's residence increased LBW by 1 percentage point at 3km from a gas well. The results for APGAR scores suggest some reduction in the score for those close to a gas well, statistically detectable at 3km. Any effect on premature birth becomes statistically detectable at 7km. This is likely a naive comparison because the observable characteristics of infants and their families with residences close (3.5km as an example) to future or existing gas wells are statistically significantly different from those of the rest of the state (see Table 1). The important thing to note is that on balance these characteristics are in the direction that one might think would not increase the prevalence of low birth weight or cause other negative birth outcomes. For example, mothers residing within 3.5km of a hydraulically fractured gas well are more likely to finish high school, more likely to attend some college (although slightly less likely to go college), less likely to be over the age of 35 and less likely to be Black or Hispanic. However, these mothers are more likely to have smoked during pregnancy, receive WIC and pay for their hospital bill with medicaid. The sample means of LBW and prematurity at 3.5km are statistically significantly lower than the mean for the rest of the state. This provides support for including these control variables in the DD design.

In light of these potential confounding observable characteristics, this paper offers a few other specifications to overcome these possible biases and confirm the robustness of the results. Table 5 shows estimates at the intensive margins using 15km, 10km and 5km as comparions groups. These results, for the 15km and 10km comparison groups, suggest an increased prevalence of LBW by 0.86 and 0.73 percentage points, respectively and a reduced APGAR score for infants born less than 3.5km of a gas well. With a 5km comparsion group, the coefficient for LBW remains positive, but is no longer statistically significant. It is quite possible that those infants born within 5km of a well are exposed to the increases in pollution and so there is little difference for these infants. However, even when compared to infants born within 5km of a gas well, those born within 3.5km still have a reduced 5 minute APGAR score. There are no detectable impacts on prematurity at any of these distances.

Another way to address the concerns that the results are driven by the comparison group is to use those residences close to permits (potential wells that have not been drilled during the sample period). Infants born to mothers who reside close to potential wells are likely to be the most similar comparion group when it comes to family and community characterstics.[13] The state chooses which permits to grant and then the gas company places their 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 well are exogenous to infant health. Table 6 shows the estimates using permits as the comparison group. Again, each column of this table represents a separate regression and demonstrates a statistically significant increase in the prevalence of LBW and a reduced APGAR score for infants born to residences that are located 2.5 and 3.5 km from a gas well, when compared to those infants born the same distances from permits. These estimates suggest that NGO within 2.5km of a mother's residence increased LBW by 1.87 percentage points, or a 26 percent increase in the prevalence of LBW in these communities (base = 0.071; 0.0187/0.071=26). This suggests that of the 2,437 births that are observed within 2.5km of a natural gas well, 46 additional were born LBW due to NGO in this sample. At 3km and 3.5km from a gas well, the incidence of LBW was increased by 1.46 and 1.27 percentage points higher, respectively. This indicates that LBW prevalence increased (on a base of 7.1 percent

[13]Comparing counties with NGO operations 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.

in these communities) by between 17.9 and 26 percent, depending on the proximity of mother's residence to NGO. As the distances increase from a nearby gas well, the estimates reduce substantially and become indistinguishable from zero at 4km. Similarly, APGAR scores are reduced at close proximities (1.5-2.5km) to gas wells. Again, premature birth does not appear to be affected by NGO and the coefficients (not statistically significant from zero) suggest mixed effects with mixed signs.

These results are corroborated by the simularity in observable characteristics (see Table 2) between those mothers who live close (2.5 or 3.5 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 NGO 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 NGO may be more likely to use WIC and Medicaid. However, when controlling for county time trends, Table 5 suggests that WIC use actually reduces after NGO.

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 resulted in reductions of LBW between 8.5-11.3 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 NGO increases the overall risk of LBW by 17.9-26 percent, depending on the proximity chosen. The direction of the estimated impacts are robust across multiple comparison groups and allows the reader the opportunity to ask different research questions.[14]

[14] For example: 1) what is the impact of NGO compared to the state? 2) what is the intensive margin of the impact? 3) what is the impact of NGO compared to similar geological locations that will likely have NGO in the future?

6 Conclusions

This paper provides estimates of the effects of natural gas operations on infant health. There are no other known studies, to date, linking NGO directly to human health at this scale. These results suggest that natural gas wells close to pregnant mothers' residences increased LBW and reduced 5 minute APGAR scores by 26% points and more than one standard deviation, respectively when compared to pregnant mothers' residences that are close to a future well (permit). These impacts are large, but not implausible given the estimates found in the literature for LBW. The estimates for 5 minute APGAR scores are similar in magnitude to those found by Almond et al. (2005) for mothers who smoked in utero. The strength of this approach is in exploiting a natural experiment that permits controls for unobservable characteristics. These results are robust across a variety of specifcations, which provides evidence of the credibility of the current research design.

Investigating the health impacts of natural gas operations is an ambitious and complicated project. The present analyses take the first steps towards estimating impacts on health at birth. These results indicate that more research on NGO and health impacts is warranted.

References

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

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.

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

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.

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.

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.

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.

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.

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.

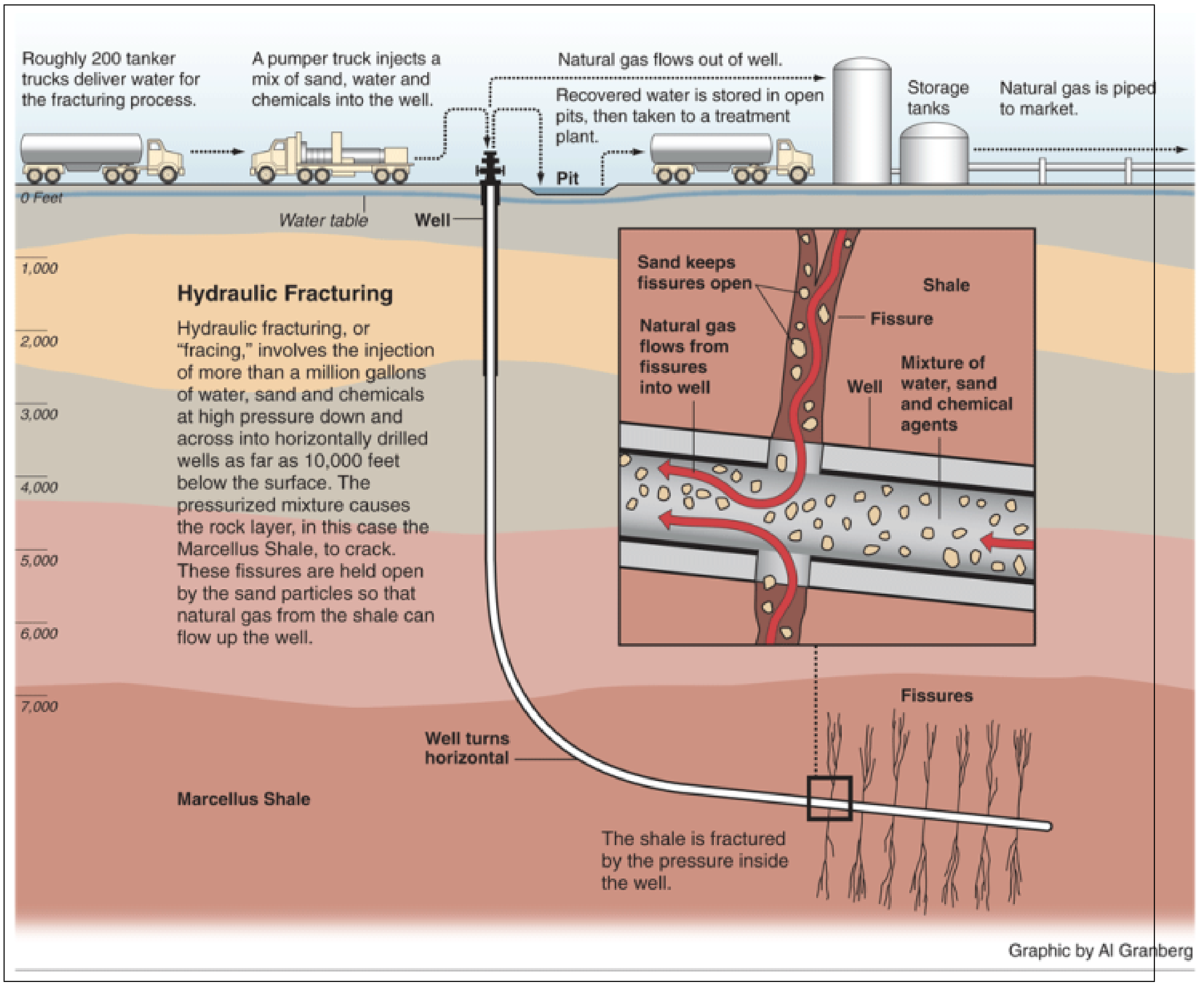

Figure 1: Graphical Representation of NGO Process

Table 1: Summary Statistics (Entire State)

	Sample means		T-ratio for diff
	Rest of Pennsylvania	3.5km from gas well/permit	
Characteristics of Birth			
Low birth weight	0.087	0.074	8.78***
Premature	0.1	0.093	4.77***
Congenital anomaly	0.005	0.005	0.74
Female	0.488	0.485	1.21
Mother's Demographic Characteristics			
High school	0.268	0.289	8.87***
Some college	0.259	0.295	15.35***
College	0.302	0.294	3.14**
Mom age (19-24)	0.261	0.272	4.47***
Mom age (20-34)	0.529	0.542	4.99***
Mom age (35+)	0.153	0.138	7.62***
Mom Black	0.158	0.032	66.72***
Mom Hispanic	0.093	0.012	53.82***
Smoked during pregnancy	0.224	0.299	33.92***
WIC recipient	0.383	0.403	7.71***
Medicaid	0.269	0.332	27.35***
Private Insurance	0.579	0.574	1.87
Observations	1107572	37438	

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

Table 2: Summary Statistics (2.5 and 3.5km from gas well or permit)

	Sample means		T-ratio for diff
	Before NGO (Permits)	After NGO	
Panel A: 2.5 km from a well or permit			
Characteristics of Birth			
Low birth weight	0.071	0.08	1.59
Premature	0.09	0.09	0.02
Congenital anomaly	0.006	0.003	1.76
Female	0.488	0.494	0.5
Mother's Demographic Characteristics			
High school	0.299	0.288	1.12
Some college	0.302	0.293	0.91
College	0.281	0.3	2.00*
Mom age (19-24)	0.273	0.27	0.38
Mom age (20-34)	0.541	0.561	1.9
Mom age (35+)	0.138	0.12	2.47*
Mom Black	0.024	0.025	0.13
Mom Hispanic	0.011	0.01	0.32
Smoked during pregnancy	0.301	0.3	0.18
WIC recipient	0.404	0.428	2.27*
Medicaid	0.33	0.373	4.25***
Private Insurance	0.575	0.554	2.04*
N	19728	2437	
Panel B: 3.5 km from a well or permit			
Characteristics of Birth			
Low birth weight	0.074	0.079	1.3
Premature	0.092	0.094	0.41
Congenital anomaly	0.005	0.003	2.04*
Female	0.485	0.483	0.24
Mother's Demographic Characteristics			
High school	0.29	0.281	1.29
Some college	0.295	0.293	0.18
College	0.292	0.31	2.56*
Mom age (19-24)	0.272	0.27	0.22
Mom age (20-34)	0.54	0.553	1.61
Mom age (35+)	0.139	0.133	1.22
Mom Black	0.032	0.033	0.49
Mom Hispanic	0.012	0.011	0.76
Smoked during pregnancy	0.3	0.29	1.42
WIC recipient	0.402	0.41	1.05
Medicaid	0.329	0.354	3.35***
Private Insurance	0.575	0.566	1.13
N	32708	4730	

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

Table 3: Testing Validity of DD Research Design: Regressions of Maternal Characteristics

	(1) High School	(2) Some College	(3) College	(4) Smoked	(5) Black	(6) Hispanic	(7) WIC
Panel 1: Within 2.5 km of a Gas Well							
Distance * NGO before birth	-0.0123	-0.0183*	0.0356***	-0.00234	-0.00264	-0.00112	-0.0106
	(0.0102)	(0.0105)	(0.0107)	(0.0103)	(0.00599)	(0.00272)	(0.0111)
R^2	0.024	0.003	0.053	0.031	0.064	0.002	0.054
Panel 2: Within 3.5 km of a Gas Well							
Distance * NGO before birth	-0.00309	-0.0122	0.0232***	-0.00552	0.00241	-0.00189	-0.0154*
	(0.00768)	(0.00791)	(0.00800)	(0.00774)	(0.00450)	(0.00204)	(0.00831)
R^2	0.024	0.003	0.053	0.031	0.064	0.002	0.054
N	183677	183677	183677	183677	183677	183677	183677

Notes: Each coefficient is from a different regression. All regressions include controls for being within distance listed of a gas well, indicators for month and year of birth, county indicators, an indicator for NGO before birth (within 15km of residence) and an indicator for specified distance from a well. Standard errors are in parentheses.

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

Table 4: Regressions of Birth Outcomes on Introduction of Natural Gas Operations (Entire State as Comparison Group)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	1km	2km	3 km	4 km	5 km	6 km	7 km	8 km	9 km	10 km
Panel 1: Low Birth Weight										
Distance * NGO before birth	0.0180	0.0074	0.0100**	0.0091**	0.0069**	0.0069**	0.0082***	0.0081***	0.0078***	0.0058**
	(0.014)	(0.007)	(0.005)	(0.0039)	(0.0033)	(0.0030)	(0.0028)	(0.0027)	(0.0027)	(0.0027)
R^2	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
N	1069699	1069699	1069699	1069699	1069699	1069699	1069699	1069699	1069699	1069699
Panel 2: Premature Birth										
Distance * NGO before birth	-0.0083	-0.0053	0.0043	0.0056	0.0046	0.0052	0.0060**	0.0058*	0.0064**	0.0026
	(0.016)	(0.0078)	(0.0053)	(0.0042)	(0.0036)	(0.0032)	(0.0030)	(0.0030)	(0.0029)	(0.0030)
R^2	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
N	1069699	1069699	1069699	1069699	1069699	1069699	1069699	1069699	1069699	1069699
Panel 3: APGAR(5 minute)										
Distance * NGO before birth	-0.0534	-0.0252	-0.0311*	-0.0167	-0.0045	-0.0079	-0.0061	-0.0066	-0.010	-0.0072
	(0.0468)	(0.0235)	(0.0160)	(0.0126)	(0.0107)	(0.0097)	(0.0094)	(0.0088)	(0.0088)	(0.0089)
R^2	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
N	1062589	1062589	1062589	1062589	1062589	1062589	1062589	1062589	1062589	1062589

Notes: Each coefficient is from a different regression. All regressions include controls for being within distance listed of a gas well, indicators for month and year of birth, county indicators, an indicator for NGO before birth (within 15km of residence), an indicator for specified distance from a well (or future well/permit) and maternal charcteristics (mother black, mother Hispanic, mother education (hs, some college, college), mother age (19-24,25-34, 35+), female child, WIC, and smoking during pregnancy. Standard errors are in parentheses.

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

Table 5: Regressions of Birth Outcomes on the Introduction of Natural Gas Operations (Intensive Margin)

	LBW (1)	Prematurity (2)	APGAR (5 minute) (3)
Panel 1: All Observations within 15 km of a well			
3.5km from gas well * NGO before birth	0.00863**	0.00425	-0.0341***
	(0.00420)	(0.00475)	(0.0129)
R^2	0.016	0.007	0.021
N	180832	180832	180151
Panel 2: All Observations within 10 km of a well			
3.5km from gas well * NGO before birth	0.00727*	0.00252	-0.0256**
	(0.00426)	(0.00485)	(0.0128)
R^2	0.014	0.006	0.017
N	114631	114631	114222
Panel 3: All observations within 5km of a well			
3.5km from gas well * NGO before birth	0.00728	0.00188	-0.0262*
	(0.00499)	(0.00570)	(0.0145)
R^2	0.014	0.006	0.012
N	51819	51819	51623

Notes: Each coefficient is from a different regression. Indicator for less than 3.5km interacted with fracking before birth is coefficient of interest. All regressions include controls for being within distance listed of a gas well, indicators for month and year of birth, county indicators, an indicator for NGO before birth (within 15km of residence), an indicator for specified distance from a well (or future well/permit) and maternal charcteristics (mother black, mother Hispanic, mother education (hs, some college, college), mother age (19-24,25-34, 35+), female child, WIC, and smoking during pregnancy. Standard errors are in parentheses.

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

Table 6: Regressions of Birth Outcomes on Introduction of Natural Gas Operations (Gas Permits as Comparison Group)

	(1) 1km	(2) 1.5 km	(3) 2km	(4) 2.5 km	(5) 3 km	(6) 3.5 km	(7) 4 km	(8) 4.5 km	(9) 5 km
Panel 1: Low Birth Weight									
Distance * NGO before birth	0.0104	0.0140	0.0141	0.0187**	0.0146**	0.0127**	0.00902	0.00661	0.00484
	(0.0190)	(0.0131)	(0.00989)	(0.00799)	(0.00704)	(0.00630)	(0.00567)	(0.00526)	(0.00496)
R^2	0.023	0.018	0.014	0.014	0.013	0.014	0.013	0.013	0.013
N	3738	8067	13903	21299	28425	35785	43882	51358	58247
Panel 2: Premature Birth									
Distance * NGO before birth	0.0145	0.00608	-0.00959	0.00133	0.00574	-0.00105	-0.00064	0.00115	0.00317
	(0.0218)	(0.0151)	(0.0114)	(0.00914)	(0.00805)	(0.00722)	(0.00647)	(0.00600)	(0.00566)
R^2	0.021	0.013	0.010	0.007	0.006	0.006	0.005	0.005	0.005
N	3738	8067	13903	21299	28425	35785	43882	51358	58247
Panel 3: APGAR (5 minute)									
Distance * NGO before birth	-0.024	-0.0875**	-0.0121	-0.0396*	-0.0259	-0.0177	-0.0203	-0.0175	-0.0144
	(0.0572)	(0.0390)	(0.0290)	(0.0236)	(0.0208)	(0.0183)	(0.0168)	(0.0155)	(0.0147)
R^2	0.031	0.019	0.014	0.012	0.012	0.012	0.011	0.011	0.011
N	3721	8036	13854	21225	28327	35660	43723	51172	58041

Notes: Each coefficient is from a different regression. All regressions include controls for being within distance listed of a gas well, indicators for month and year of birth, county indicators, an indicator for NGO before birth (within 15km of residence), an indicator for specified distance from a well (or future well/permit) and maternal charcteristics (mother black, mother Hispanic, mother education (hs, some college, college), mother age (19-24,25-34, 35+), female child, WIC, and smoking during pregnancy. Standard errors are in parentheses.

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