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Shale gas development and infant health: Evidence from Pennsylvania☆

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ABSTRACT

This research exploits the introduction of shale gas wells in Pennsylvania in response to growing controversy around the drilling method of hydraulic fracturing. Using detailed location data on maternal addresses and GIS coordinates of gas wells, this study examines singleton births to mothers residing close to a shale gas well from 2003 to 2010 in Pennsylvania. The introduction of drilling increased low birth weight and decreased term birth weight on average among mothers living within 2.5 km of a well compared to mothers living within 2.5 km of a permitted well. Adverse effects were also detected using measures such as small for gestational age and APGAR scores, while no effects on gestation periods were found. In the intensive margin, an additional well is associated with a 7 percent increase in low birth weight, a 5 g reduction in term birth weight and a 3 percent increase in premature birth. These results are robust to other measures of infant health, many changes in specification and falsification tests. These findings suggest that shale gas development poses significant risks to human health.

The United States (US) holds large unconventional gas reserves in relatively impermeable media such as coal beds, shale, and tight gas sands, which together with Canada account for virtually all commercial shale gas produced in the world (IEA, 2012).[1] 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.[2] In 2010, unconventional gas production was nearly 60% of total gas production in the US (IEA, 2012). Natural gas from the Marcellus formation, particularly in Pennsylvania, currently accounts for the majority of this production (Rahm et al., 2013).[3] A recent assessment by The Wall Street Journal estimates that over 15 million Americans live within 1 mile of an oil or gas well drilled since 2000 in 11 of the 33 states where drilling is taking place (Gold and McGinty, 2013). With this expansion, it is becoming increasingly common for shale gas development to take place in close proximity to where people live, work and play.

The expansion of shale gas development (SGD) in the US has brought with it a national debate that seemingly lacks a consensus over its economic, environmental, health and social implications. There is growing evidence that shale gas development creates jobs and generates income for local residents in the short run (Allcott and Keniston, 2014; Bartik et al., 2016; Feyrer et al., 2017; Hausman

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[1] The International Energy Agency (IEA) defines unconventional gas as sources of gas trapped in impermeable rock deep underground.

[2] Hydraulic fracturing (popularly known as "fracking" or "fracing") stimulates the well using a combination of large quantities of water ("high-volume"), fracturing chemicals ("slick water") and sand that are injected underground at high pressure. This process fractures the rock and causes the resource to be released.

[3] Pennsylvania experienced very rapid development of shale gas, with 4272 shale gas wells drilled from 2007 to 2010 (PADEP, 2010a).

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and Kellogg, 2015; Mason et al., 2015). In addition to its economic benefits, many claim that a move to natural gas (and away from petroleum- or coal-based energy) will support U.S. energy independence and national security. Shale gas provides an attractive source of energy because it emits fewer pollutants (e.g., carbon dioxide, sulfur dioxide, nitrogen oxides, carbon monoxide and particulate matter) when burned than coal and other fossil-fuel energy sources per unit of heat produced (Chen et al., 2017). Globally, the shale boom has improved ambient air quality and displaced coal-based electricity, especially for areas with coal-fired power plants (Johnsen et al., 2016). However, these benefits may come with local costs associated with drilling activity in communities where it takes place. These costs may include reduced environmental quality through local air pollution (Colborn et al., 2012; Litovitz et al., 2013; Witter et al., 2013), water contamination (Warner et al., 2012; Olmstead et al., 2013; Hill and Ma, 2017), increased truck traffic (Graham et al., 2015) and health. Concerns over perceived ground water contamination have caused a discount of housing prices to compensate for the risk and an approximately $19 million increase in bottled water purchases in 2010 in response to SGD in Pennsylvania (Muehlenbachs et al., 2015; Wrenn et al., 2016). This is further supported by a recent cost–benefit analysis that found substantial environmental costs associated with health damages from air pollution emitted by SGD totaling $27.2 billion (Loomis and Haefele, 2017).

In utero exposure to air pollution has been linked to adverse birth outcomes, lower educational attainment, labor market outcomes and future health problems (see Currie and Schmieder, 2009; Currie, 2009; Currie et al., 2014 for summaries of this research). In particular, a large literature has linked air pollution (e.g. particulate matter (PM), carbon monoxide (CO), sulfur dioxide ($S0_2$), nitrogen oxide (NO_x)) from coal-fired power plants with low birth weight, premature birth and infant mortality both within the US and in the developing world.[4] With natural gas touted as a transition fuel between coal-based electricity and renewable options, infant health is one way to compare costs across alternative options. While coal is undeniably worse than natural gas with respect to resource extraction and energy generation, concerns regarding emissions associated with shale gas should be studied (Chen et al., 2017).

The impact of shale gas development on health has become the focus of a growing body of literature. To my knowledge, Hill (2012) is the first study to assess the impact of shale gas development on infant health. Concurrent health studies include case studies (Bamberger and Oswald, 2012), health impact assessments (McKenzie et al., 2012), toxicological assessments of specific chemicals (Colborn et al., 2011), self-reported health symptoms (Ferrar et al., 2013) and studies exploiting administrative records such as birth certificates, hospital records or electronic medical records (EMR) to study asthma, pneumonia, fatigue, migraine, sinus effects, and birth outcomes (Hill, 2013; McKenzie et al., 2014; Stacy et al., 2015a; Rasmussen et al., 2016; Casey et al., 2016; Tustin et al., 2017; Currie et al., 2017; Whitworth et al., 2017; Peng et al., 2018).[5] All but one of the infant health studies find a positive association between drilling and poor birth outcomes measured by premature/preterm birth (PTB) or low birth weight (LBW). Due to a lack of consistency in outcomes, proximity, and exposure metrics used, it is challenging to compare findings across these studies.

To assess the impact of shale gas development on infant health, I build a unique database that contains the longitude and latitude of all shale gas wells, the street address (geocoded) of all new mothers, and data on whether the mother's address falls within public water service areas. To define a treatment variable, I exploit both the timing of drilling activity (using the "spud date," or the date the drilling rig begins to drill a well) and the exact locations of well heads relative to residences. I then use as a comparison group mothers who live in proximity to future wells, as designated by well permits. The exact locations of both wells and mothers' residences allow me to exploit variation in the effect of shale gas drilling within small, relatively homogeneous socio-economic groups, and the timing of the start of drilling allows me to confirm the absence of substantive pre-existing differences. Through this method, I am able to provide robust estimates of the impact of maternal exposure to shale gas development during pregnancy on birth outcomes.

The main results suggest both statistically and economically significant effects on infant health. I find that shale gas development increased the incidence of low birth weight and small for gestational age in the vicinity of a shale gas well by 24 percent and 18 percent, respectively. Furthermore, term birth weight and birth weight were decreased by 49.6 g (1.5 percent) and 46.6 g (1.4 percent), on average, respectively and the prevalence of APGAR scores less than 8 increased by 26 percent. Results for premature birth were mixed and sensitive to specification. The difference-in-differences research design, which relies on the common trends assumption, is tested by examining the observable characteristics of the mothers in these two groups before and after development, testing for pretrends in the outcome variables using the sample before drilling, permit dates only, and future wells only, and using a random date to define treatment. The research design is robust to these tests as well as a range of specifications. I examine mobility using the group of mothers with more than one birth and find that there is little evidence of moms moving in response to drilling.

This paper contributes to the literature using a quasi-experimental design and is a combination of the strengths of both the epidemiologic and economic literature described above. First, I improve upon the epidemiologic literature by employing a difference-in-differences design. In particular, I exploit the exogeneity of drilling conditional on leasing and permitting, which results in statistically homogenous treated and comparison groups. This provides a more stable comparison group than in Currie et al. (2017) that compares to those living within 3–15 km. Second, I improve upon the economics literature by using the strengths of the epidemiologic literature by looking at multiple measures of adverse infant health outcomes which may be indicative of different aspects of drilling exposure. Preterm birth is indicative of preterm premature rupture of membranes, which can result from genetics, stress or low socio-economic status (SES) (Goldenberg et al., 2008). Low birth weight and small for gestational age (SGA) are more related to intrauterine growth restriction (IUGR), which is more consistently related to air pollution (Stieb et al., 2012b; Sun et al., 2015; WHO, 2005). Congenital abnormalities indicate exposure to a teratogen during pregnancy. Given the inconsistency in measured outcomes in existing studies, I simultaneously estimate impacts for all outcomes within the same sample and identification strategy. This is particularly useful for policy given the mixed findings in the existing studies and that none of these studies directly test exposure mechanisms. Third, I improve upon the economics literature by thoroughly controlling for predictors of infant health and estimating the extensive and intensive margins of drilling. I include controls for insurance status, WIC, previous risky pregnancy, parity, and smoking status. I also measure heterogeneity across SES sub-

[4] See Chay and Greenstone (2003a), Currie and Neidell (2005), Jayachandran (2009), Tanaka (2015), Knittel et al. (2015), Sanders and Stoecker (2015), Clay et al. (2016), Eva et al. (2016), Yang et al. (2017), Yang and Chou (2017), Severnini (2017), Jha and Muller (2017). For example, Yang et al. (2017) found that after a power plant in PA closed down, low birth weight declined by 15 percent and premature birth decline by 28 percent due to reductions in $PM_{2.5}$ and $S0_2$.

[5] See Colborn et al. (2011) regarding health effects of fracturing chemicals; see McKenzie et al. (2012) for a review of studies investigating the effects of inhalation exposure; see Vengosh et al. (2014) for a review of the likely effects of water contamination from SGD; see Werner et al. (2015), Stacy (2017), and Balise et al. (2016) for recent reviews of SGD and health related studies.