SHALE DEVELOPMENT: RISKS, RESPONSES, AND REGULATION

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To my beloved husband Piotr

To my wonderful parents

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LIST OF ABBREVIATIONS

ACS: American Community Survey

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act

CGL: Commercial general liability

CWA: Clean Water Act

DRBC: Delaware River Basin Commission

EH&S: Environmental, health, and safety

EIL: Environmental impairment liability

EPA: Environmental Protection Agency

FDA: Food and Drug Administration

FOIL: New York's Freedom of Information Law

GIS: Geographic Information System

IEA: International Energy Agency

NYDEC: New York Department of Environmental Conservation

PADEP: Pennsylvania Department of Environmental Protection

PASDA: Pennsylvania Spatial Data Access

RCRA: Resource Conservation and Recovery Act

SDWA: Safe Drinking Water Act

SGEIS: Supplemental Generic Environmental Impact Statement

STRONGER: State Review of Oil and Natural Gas Environmental Regulations, Inc.

INTRODUCTION

Natural gas production has expanded rapidly in the United States in the last decade, largely due to a high natural gas price in the mid-2000s and technological advances that have made shale gas production economically viable (U.S. Energy Information Administration 2011). Deep shale formations have long been known to hold large quantities of oil and gas, but their characteristically low permeability made extraction challenging and previously unprofitable. In recent years, operators have combined two techniques to increase shale well productivity: horizontal drilling, which exposes more shale rock to the wellbore; and high-volume hydraulic fracturing (fracking), which injects large quantities of water mixed with chemicals and sand at high pressure to create and prop open tiny fractures that allow trapped gas to flow into the wellbore (U.S. Department of Energy 2013). These techniques are not new, but their widespread use in recent years has highlighted outstanding scientific uncertainty about the environmental, health, and safety impacts of rapid and extensive shale development (U.S. Government Accountability Office 2012).

In this dissertation, I examine responses to perceived risks of shale development as revealed through property transactions and through the political process. In Chapter I, I use property sales data from Washington County, Pennsylvania to analyze how individuals evaluate the risks of nearby shale development. I find evidence that individuals differentiate between nearby vertical wells, which are not likely to be shale wells, and nearby horizontal wells, which are likely to employ high-volume fracking. Although an additional horizontal well within a mile of a property tends to increase the property's value, this positive effect is diminished for properties that rely on private wells for drinking water. In addition, the values of all properties with a nearby horizontal well decrease when state regulators find and reveal high numbers of environmental, health, and safety violations at shale wells. Thus, Chapter I demonstrates that perceived risks of shale development can cause real losses to property values. My findings suggest, however, that shale development could pass a local benefit-cost test—wherein winners could more than compensate losers —if drilling risks are well managed.

Chapter II then considers when individuals collectively decide to ban shale development outright. Numerous cities and towns across the United States have started to prohibit all natural gas extraction activities, and such local bans could hinder a national energy policy that relies on continued increases in natural gas production. This chapter investigates the circumstances under which local governments are likely to ban shale development by analyzing New York town decisions. Since July 2008, New York has had a moratorium on fracking activities to allow the state to research appropriate regulations. In the meantime, more than fifty towns have adopted bans and more than one hundred and twenty towns have adopted additional moratoria on fracking activities. In this chapter, I assess the relative importance of risk perceptions and economic and political factors in these decisions. In particular, I find that greater reliance on private wells for human and animal consumption is associated with a higher probability of adopting a ban. The decision to adopt a moratorium, which is largely symbolic in light of New York's statewide moratorium, appears to be driven by environmental preferences. Again, my results suggest that perceived risks to water sources play an important role when individuals assess the relative costs and benefits of allowing shale development in their communities.

In Chapter III, I discuss how governments could better manage the water-contamination risks of shale development. Key to this management is creating a system that ensures the quick discovery of any possible contamination, incentivizes net-beneficial risk management, and guarantees the availability of funds to remediate environmental harms. I first divide risks into four categories based on the nature of the pollution releases and the manifestation of harm, and I suggest that governments should manage these risk categories differently. The resulting comprehensive system would use combinations of regulations, tort liability, and insurance mandates to ensure that operators are liable for all environmental risks, thus stimulating an efficient level of shale-development activity, and would guarantee a process for the remediation of any residual environmental harms, alleviating some of the water-contamination concerns identified in Chapters I and II.

Overall, this dissertation makes the following contributions to law and economics: it employs empirical analysis to examine the perceived risks of shale development as revealed through property transactions in a Pennsylvania county and through legislative decisions by New York towns. In general, I find that risks to water feature prominently in both contexts. I then consider legal and regulatory interventions that could better manage risks to water, thereby possibly preventing property-value losses and outright bans. I hope that this dissertation will provide timely, fact-driven, and useful information to policymakers and citizens evaluating the future of shale development.

CHAPTER I

PROPERTY VALUES AND RISKS: EVIDENCE FROM SHALE DEVELOPMENT

Introduction

The profitability of extracting oil and gas trapped within the nation's extensive shale formations has generated a boom in the oil-and-gas industry.[1] Operators are pushing to drill close to populations and sensitive resources, and many states are facilitating such extensive drilling with laws that preempt local control. Shale production, however, is not without local risks. The unprecedented scope and scale of development exposes more areas to ordinary perils associated with drilling activities, including air pollution and spills, accidents, and blowouts, the cumulative effects of which could be significant. In addition, shale drilling techniques, namely horizontal drilling and high-volume hydraulic fracturing (fracking),[2] come with their own set of hazards, such as possible groundwater and surface water contamination from fracking fluid or wastewater, water-supply shortages due to the sizeable water requirements associated with fracking, and earthquakes induced through the injection of wastewater into disposal wells. Some of these risks are speculative, and the magnitudes of the risks are uncertain.

Nonetheless, people across the United States must decide whether to lease their mineral rights to drilling operators. A rational homeowner in this position would weigh

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[1] These formations are also referred to as unconventional formations.

[2] Shale wells require high-volume hydraulic fracturing or horizontal drilling techniques to stimulate well production. Most vertical (and usually conventional) wells are also hydraulically fractured, but the volume of fluid typically required for well stimulation is much lower.

the expected rental and royalty payments received from oil-and-gas companies against the expected costs of adverse drilling events, gleaned from currently available risk information from neighbors, the scientific community, the media, state regulators, and the companies themselves. Over time, a rational homeowner would update his perception of the benefits and costs of the arrangement based on any new information that he obtains. If he no longer perceives the benefits to outweigh the costs (enough to justify the costs of moving), then the homeowner would move to another location, one that is farther from the risks of drilling. A rational homebuyer would also weigh expected benefits and costs when deciding whether to purchase a property near such drilling, just as he weighs the benefits and costs of any other property or neighborhood characteristic in his decision. The fact that the property comes with an oil-and-gas lease that accrues rental and royalty payments could be a plus, but any perceived risks from drilling would diminish the advantages of such a lease. In this way, final sales prices for homes would reflect perceptions of the average net benefits or net costs of shale drilling as thousands of homeowners and homebuyers weigh their options.

In this chapter, I analyze property sales data from Washington County, Pennsylvania between January 2004 and May 2013 to explore individuals' willingness to pay to live near shale development as compared to conventional development under different circumstances. I focus on Pennsylvania for a number of reasons. For one, Pennsylvania is an important player in the shale boom. By 2012, the state became the third-largest gas-producing state, and preliminary estimates suggest that it could have become the second-largest producer in 2013—mostly due to the huge growth in Marcellus shale production (U.S. Energy Information Administration 2013).

Pennsylvania also has the second-highest number of households served by private water wells, making Pennsylvania homeowners particularly vulnerable to possible groundwater contamination from shale development.[3] In addition, Pennsylvania has been active in passing various laws and regulations regarding shale development. Most controversial was the legislature's February 2012 law, known as Act 13, that imposed additional requirements on shale well operators and gave all operators the right to drill anywhere notwithstanding local zoning that might prohibit drilling in sensitive areas, such as residential areas.[4] A study on how drilling affects property values could shed light on the value of regulating shale wells more stringently and prohibiting local regulation. Finally, Pennsylvania has a wealth of publicly available data on well locations and violations.

I focus on Washington County in particular because it is the highest shale-producing Pennsylvania county for which I have property sales data.[5] Washington County also has a history of conventional development, making it ideal for an analysis of possible diverse property-value effects of conventional versus unconventional production.[6] Finally, two other studies analyze property-value impacts in Washington County using different empirical strategies (Gopalakrishnan and Klaiber 2014; Muehlenbachs, Spiller, and Timmins 2012), allowing for comparisons of results and providing a complete picture of the local impacts in one county.[7]

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[3] "Groundwater Supply and Use," http://wellowner.org/groundwater/groundwater-supply-use/.

[4] 58 Pa. Cons. Stat. §§ 2301–3504 (2013), which amends the Oil and Gas Act (Title 58). In December 2013, the Pennsylvania Supreme Court declared unconstitutional the part of Act 13 that bars local zoning restrictions. Robinson Twp., Washington Cnty. v. Com., 2013 WL 6687290 (Pa. Dec. 19, 2013).

[5] Laura Legere and Katie Colaneri. 2014. "Pennsylvania Shale Production Continued to Grow in 2013." *StateImpact*, February 19. DataQuick did not provide sales data for the counties with higher shale production.

[6] Michael Jacobson and Timothy W. Kelsey. 2011. "Impacts of Marcellus Shale Development on Municipal Governments in Susquehanna and Washington Counties, 2010." Marcellus Education Fact Sheet, Pennsylvania State University.

[7] In Appendix A, I discuss the potential generalizability of results to other counties in Pennsylvania.

This chapter is the first to distinguish the property-value effects of nearby vertical and horizontal wells and to identify property-value effects based on the number of recent environmental well violations. Horizontal and vertical well pads look different, and they may generate different average benefits and costs to nearby property owners. For example, because horizontal wells have a longer reach, properties located a certain distance from a horizontal well's wellbore are more likely to receive royalty and rental payments than are properties located the same distance away from a vertical well's wellbore. On the other hand, horizontal wells require high-volume fracking, and the risks that stem from the application of horizontal drilling and high-volume fracking are those that are uncertain. In particular, owners may be concerned about water contamination, especially if their properties are vulnerable to such contamination, such as properties that rely on private wells for drinking water. Finally, individuals might look to recent information on well violations to update their risk preferences, but again, their desire for risk information might also vary by well type. Individuals may be more interested in violations that occur at horizontal wells given the risk uncertainty, and only properties with nearby wells might suffer negative effects from a high number of recent well violations. My results are consistent with such effects.

I find that an additional horizontal well within a mile of a property increases the property's value, likely due to the receipt of rental and royalty payments. I do not find any statistically significant property-value effects of the number of vertical wells within a mile. In addition, properties that rely on private wells for drinking water face a property-value loss from each additional nearby horizontal well, but the property-value loss does not fully offset the benefit of an additional well on average. Finally, properties with nearby horizontal wells face losses in value as the number of relevant well violations in the county six months prior to each property's sale increase. These results suggest that individuals perceive groundwater risks from nearby shale development. County-level violations inform individuals' perceptions of these and other risks, but property-value effects are largely limited to properties with nearby horizontal wells.

The Homeowner's Decision and Property Values

In Pennsylvania, most property owners possess both "surface rights" and "mineral rights," meaning that an oil-and-gas operator seeking to drill a well spanning several property tracts would need to receive permission from all of the relevant property owners.[8] Landowners typically accept rental and royalty payments from oil-and-gas companies in exchange for leasing mineral rights to operators. Before production begins, most landowners receive annual rental payments, varying from a few dollars to hundreds of dollars per acre, that usually end once production-tied royalty payments begin. In Pennsylvania, a recent state law requires the production-tied royalty payments to be at least 12.5 percent of the value of the produced oil or gas, and landowners can negotiate higher royalty payments.[9] In this way, landowners may receive payments from nearby testing and exploration activities for a few years before any drilling commences, and

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[8] In Pennsylvania, the Oil and Gas Conservation Law prevents waste of mineral resources by allowing operators to apply to the Oil and Gas Conservation Commission to force pooling of landowners into a drilling unit. 58 Pa. Cons. Stat. §§ 401–19 (2013). Compulsory pooling prevents a landowner from holding up oil-and-gas extraction by refusing to enter into a lease, and it prevents an operator from draining mineral resources from neighboring properties without paying rental and royalty payments. Compulsory pooling, however, does not apply to production from the Marcellus shale.

[9] 58 Pa. Cons. Stat. § 33.3 (2013), codifying the 2013 Oil and Gas Lease Act.

these payments have the potential to greatly increase and continue for a number of years once drilling commences.

In deciding whether to lease mineral rights, a landowner that lives on her property—in other words, a homeowner—must weigh these rental and royalty payments against the potential adverse environmental, health, and safety effects of nearby drilling. In particular, the media often focuses on the potential water contamination that could result from fracking fluids, which can contain hazardous substances, fracking wastewater, and methane gas.[10] In fact, leaks and spills often occur at drilling sites, as evident from information on well violations. The Pennsylvania Department of Environmental Protection (PADEP), the agency that oversees oil and gas activities in the state, strives to frequently monitor and inspect producing wells.[11] PADEP schedules inspections of producing wells, paying particular attention to wells that are about to be fracked, and responds to citizen or operator reports of spills and other harms. The agency then posts information on any resulting violations on its website, information that is often reported on by various media outlets. Using this information, researchers have identified almost one hundred and fifty violations for minor spills (spilling less than four hundred gallons) and nine violations for major spills in Pennsylvania between January 2008 and August 2011 (Considine et al. 2013).

After weighing the benefits and costs, homeowners decide whether to enter into an oil-and-gas lease. If they later decide to sell their homes, they may face property-value

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[10] Appendix C provides a detailed overview of some of these risks.

[11] This discussion of PADEP's regulatory policy is based on conversations with the agency's oil and gas office in October 2013 as well as on information from numerous reviews done by the State Review of Oil and Natural Gas Environmental Regulations, Inc. (STRONGER) (STRONGER 2010; STRONGER 2013). STRONGER is a nonprofit, multi-stakeholder organization that provides voluntary reviews of state oil and gas laws and regulations, and Pennsylvania's program has undergone five reviews.

gains or losses based on their decision to lease, as homebuyers will assess a property based on its characteristics, which include both the benefits and costs of nearby wells. Properties with nearby wells that do not receive rental or royalty payments would face only the costs of drilling activities, likely facing property-value losses unless potential buyers expect future drilling activity on their property with resulting rental and royalty payments. On the other hand, properties that rely on private water wells, whether receiving rental and royalty payments or not, may be more vulnerable to water-contamination risks, which may decrease property values.

A hedonic housing price model provides a tool for studying how individuals value nearby environmental amenities and disamenities. Hedonic housing price models are based on the theory that, in equilibrium, the price homebuyers pay for a house is related to the characteristics of the house, which include the structural attributes of the house as well as neighborhood attributes such as environmental quality (Rosen 1974). Homebuyers make tradeoffs between the property price and combinations of these characteristics, revealing their preferences through their purchases. When researchers analyze a collection of purchases of different bundles, they can estimate the implicit marginal price of one of the characteristics by examining how the total price changes when this characteristic changes, holding other relevant characteristics constant. Hedonic housing price models have been used to analyze valuations of locally undesirable land uses, such as power plants (Davis 2011), hog operations (Palmquist, Roka, and Vukina 1997), underground storage tanks (Guignet 2013), facilities that report to the Toxic Release Inventory (Banzhaf and Walsh 2008), and contaminated sites (Gayer, Hamilton, and Viscusi 2000; Kiel and Williams 2007; Greenstone and Gallagher 2008).

Two previous studies examined property-value effects of additional oil-and-gas wells in Washington County, Pennsylvania using a hedonic housing price model.[12] Gopalakrishnan and Klaiber (2014) analyzed property sales data from 2008 to 2010 to estimate the impact of an additional recently permitted horizontal well on nearby properties. The authors found that all properties face value losses with each additional new well, and properties that rely on private wells for drinking water have larger losses. The authors found the largest losses, however, accruing to properties surrounded by agricultural lands, suggesting a concern with future nearby development. The authors did not include the number of nearby vertical (or older horizontal) wells in their regressions and did not control for any tract-level neighborhood characteristics. Muehlenbachs, Spiller, and Timmins (2012) analyzed property sales data from 2004 to 2009 to find that an additional drilled well pad (of any type) generally increases nearby property values, but again, properties that rely on private water wells face property-value losses.[13] When the authors limited their sample to properties located just inside and outside the public water service boundary and employed property fixed effects, they found especially large and statistically significant value losses of an additional drilled well pad for properties that rely on private water wells. This chapter extends these analyses by distinguishing the effects of nearby vertical and horizontal wells and examining the effect of information on well violations on property sales over a longer time frame, while controlling for property, neighborhood, and other characteristics in cross-sectional regressions and employing a nearest-neighbor matching estimation strategy as an additional check.

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[12] Another study has considered property-value effects in a larger region of Pennsylvania and New York (Muehlenbachs, Spiller, and Timmins 2014).

[13] The authors consider all wellbores that are within one acre of another wellbore to be on the same well pad.

Hypotheses

In this chapter, I use a hedonic housing price model to capture the willingness to pay associated with different features of nearby wells. I expect individuals to care about nearby wells for a number of reasons, namely because wells may increase income through royalty or rental payments; wells may be visually, audibly, or otherwise displeasing; and wells may increase the risk of poor water quality and other bad outcomes associated with drilling. In this section, I discuss my specific hypotheses.

One component of the direct marginal price effect of an additional well within a mile of the property is the expected rental or royalty payments minus any visual, audible, or environmental (or, for simplicity, environmental) disamenities associated with the presence of the well. If the average rental and royalty payments are large enough, then the direct effect on nearby properties may still be positive; otherwise, these two forces may offset each other. If some environmental disamenities such as environmental risks are considered separately, however, then the effect of an additional nearby well on nearby property values may become positive because of the rental and royalty payments that accrue to some of these properties.

> *Hypothesis 1. After controlling for environmental disamenities, an additional well should increase nearby property values.*

Importantly, I expect these effects to be different for nearby vertical and horizontal wells. First, horizontal wells will pay rental and royalty payments to more nearby property owners on average, increasing the direct positive effects. Operators of horizontal wells can drill under properties located up to two miles away from the wellbore, which means that these operators tend to pay rental and royalty payments to more surface owners than do operators of a typical vertical well. Second, property owners without oil-and-gas leases may be more aware of, and more concerned about, nearby horizontal drilling activities. Property owners are more likely to be aware of nearby shale wells partly because recent surface-owner notification requirements vary in Pennsylvania depending on well type. An applicant for a permit to drill a conventional well must only notify surface owners within 1,000 feet, or about 0.2 miles, of the wellbore, while an applicant for a permit to drill a shale well must notify surface owners within 3,000 feet, or about 0.6 miles, of the wellbore.[14] But even residents aware of both vertical and horizontal drilling could have different concerns about the two types of drilling operations. Vertical and horizontal well pads are visibly different in nature and size. A typical Marcellus well pad involves multiple horizontal wells and covers about five acres (U.S. Department of Energy 2013), while vertical wells are spaced at least twenty to forty acres apart in order to maximize production. In addition, the high-volume fracking process necessary to stimulate horizontal well production requires multiple trucks to transport gallons of water, sand, and chemicals to the fracking site each day and may present different risks of spills and leaks. These differences suggest that residents, especially residents of a county with prior experience with conventional drilling, are likely to know whether nearby wells are vertical or horizontal and may associate vertical and horizontal wells with different risks. Property values may manifest any such differences in individuals' subjective risk perceptions of these two types of wells. Hence, each of my hypotheses is associated with an additional hypothesis based on well type.

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[14] 58 Pa. Cons. Stat. § 3211(b) (2013).

> *Hypothesis 1A. An additional horizontal well affects nearby property values more than does an additional vertical well. I expect both positive effects from royalty payments and negative effects from risks to water to be larger in magnitude for nearby horizontal wells.*

Pennsylvania residents vulnerable to groundwater contamination may be particularly concerned about drilling-related risks. More than a million Pennsylvania households rely on private water wells. Unlike for the public water system, Pennsylvania has no statewide regulations governing the location, testing, and treatment of private water wells, making it up to the individual homeowner to ensure that his water supply is safe for consumption. Properties that rely on private water wells, therefore, would be expected to have a higher probability of realizing poor water quality if a nearby well damages water sources.[15]

> *Hypothesis 2. An additional well will decrease the value of nearby properties that rely on private water wells.*

Because horizontal well drilling employs high-volume fracking and because the extensive reach of horizontal wells exposes more areas to risks, individuals may perceive a higher probability of poor water quality from nearby horizontal wells.

> *Hypothesis 2A. An additional horizontal well will have a greater negative effect on the value of nearby properties that rely on private water wells than will an additional vertical well.*

Finally, when individuals make decisions under conditions of uncertainty, it is important to consider the information that they use to form their subjective risk perceptions (Viscusi, Magat, and Huber 1987; Smith and Johnson 1988; Maani and Kask

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[15] Anecdotally, a Pennsylvania realtor has said about one property, "If [the property] had public water today, I could probably sell it for $120,000. . . . Right now with no water, we got it listed at $87,900. It's not gonna sell because other houses in the area without water are selling for between $15,000 and $30,000." Susan Phillips. 2012. "Residents Fed Up with Bad Water Flee Shale Drilling Areas." *StateImpact Pennsylvania*, April 30. The realtor also stated that houses with publicly supplied water are rising in value because residents want a secure water source.

1991). In this case, because homeowners and homebuyers do not have perfect information on risks, they may seek out and respond to additional information, such as information on environmental, health, and safety (EH&S) well violations. This information can provide residents with a better sense of common types of violations during drilling activities. Unlike other risk information in this context, information on well violations is readily available as violations are posted on the PADEP website and may be reported on by local newspapers. People can view well violations by visiting the state agency website, examining media sources, or receiving information directly from PADEP. In addition, the diffusion of information within the local real estate market can influence the perceptions of individuals who do not personally view this information (Gayer, Hamilton, and Viscusi 2000). When people obtain new information that clarifies uncertain risks, property values may update to reflect this new understanding.[16] I expect information on the number of well violations to increase individuals' subjective probabilities of adverse events because individuals likely place high weight on violations information.[17] Such behavior would be consistent with a Bayesian learning process (Gayer, Hamilton, and Viscusi 2000).

> *Hypothesis 3. An additional environmental, health, and safety well violation in the county will reduce the value of properties with nearby wells.*

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[16] For example, Gayer, Hamilton, and Viscusi (2000) found that the U.S. Environmental Protection Agency's release of site-specific risk information generally lowered individuals' perceptions of a Superfund site's risk, a result that suggests that the initial reactions to site risks were too high.

[17] In addition, increases in subjective risk perceptions could be aided by various biases and heuristics that individuals use to process risk information, even if actual frequencies of adverse events implied by the rate of violations are low. Previous researchers have found that individuals are susceptible to an availability bias, meaning that they often judge the probability of events based in part on the ease with which examples of these events come to their mind (Tversky and Kahneman 1973). This concept has been tested empirically (*e.g.*, Lichtenstein et al. 1978; Bin and Landry 2013). Experiences might also matter. As the number of violations increase, the number of people who personally experienced an adverse well event increases. People might view experienced events as more likely or informative, and this might also drive increasing subjective risk perceptions.

Because individuals have experience with nearby vertical wells, they might not seek out additional information on vertical well risks; they might only seek out information on the new risks of horizontal wells in order to reduce the risk uncertainty associated with horizontal wells that are fracked. As shale wells are likely to be horizontal wells that employ fracking, individuals would look to the most informative information available: information on EH&S violations at shale wells. Well-violation information would then decrease property values through its influence in increasing the subjective risk probability associated with having a nearby horizontal well.

> *Hypothesis 3A. Higher numbers of recent well violations will reduce the value of properties with a nearby horizontal well more than properties with a nearby vertical well.*

Data Description

To test my hypotheses, I use property sales data from DataQuick, a national real-estate data company. My dataset includes all sales between January 2004 and May 2013 for Washington County, Pennsylvania. DataQuick provides information on each property's structural characteristics as well as information on all sales of the property. I limited my analysis to single-family residential properties. The property structural variables include the number of bedrooms, the number of bathrooms, the size of the lot in square feet, the age of the property, and the presence of a garage, among other things. I removed properties that do not have a sale price, have a zero sale price, are indicated to be non-arms length transactions, or have zero square footage. In order to obtain latitude and longitude coordinates for each property, I used Geographic Information System (GIS) technology to geocode each property and kept only properties that were located with building-level accuracy. Finally, I used the Consumer Price Index to express all property sales prices in constant 2012 dollars. I present summary statistics in Table 1. The average sale price is $161,344. Properties on average contain three bedrooms and two bathrooms and are about fifty years old.[18]

In addition to property sales data, I obtained information on the exact locations of drilled wells within each county using data from the PADEP. I calculated distances from each property to the nearest 350 wells. I then merged each well identifier with relevant well characteristics, ultimately using this information to calculate the number of wells satisfying various criteria within a set distance from each property. For example, in my main analysis, I use the numbers of vertical and horizontal wells within a mile of each property that have been drilled prior to the property's sale date. In robustness checks, I vary the distance around each property and the immediacy of drilling relative to the date of sale. Properties in Washington County have, on average, 0.17 horizontal wells within one mile.

I also obtained information on well violations from PADEP. I generated variables capturing the number of EH&S violations that accrued to wells within the county in the six months prior to the property's sale. EH&S violations include discharging industrial waste and other pollution to Pennsylvania waters without a permit and failing to mitigate spill impacts, and these violations can accrue to operators of conventional or shale wells. I chose six months prior to each property's sale as a reasonable time window during which individuals may seek and process information on well violations. After a violation is discovered, it must be posted on the PADEP website. In addition, individuals need time

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[18] Gopalakrishnan and Klaiber (2014) and Muehlenbachs, Spiller, and Timmins (2012) also used data from DataQuick in their analyses of Washington County, Pennsylvania. As expected, our summary statistics are similar, although our analyses focus on different time periods.

to view and process the information. The information is also salient for at least a few months because homebuyers take time to search for a new home.

To identify properties that rely on private water wells, I used data on Public Water Supplier's Service Areas in Pennsylvania from the Pennsylvania Spatial Data Access (PASDA). Owners of properties that lie outside of the public water service area are likely to rely on private wells for drinking water because it is expensive to extend piped water outside of the service area. Therefore, I used GIS technology to identify those properties that fell outside of the public water service areas and treated those as properties that rely on private water wells. In Washington County, about eight percent of properties rely on private water wells.

In addition, I controlled for neighborhood characteristics by matching each property to census tract-level characteristics from the American Community Survey using GIS technology. These characteristics include the median household income; the percent of the population under nineteen years old; the percent of the population that is Black; and the percent of the population, twenty-five years old or older, that graduated high school for the year 2008, which is approximately the midpoint of my 2004 to 2013 sample. I also used data from PASDA to match each property to its school district in order to include school district fixed effects in my regressions.

Empirical Specification

To test my hypotheses, I regress the natural logarithm of the sale price for property *i* at time *t* ($\ln P_{it}$) on the number of nearby wells drilled prior to the property's sale; a vector of the property's structural characteristics (X); a vector of the property's neighborhood characteristics (N); and city, school district, and year fixed effects (C_i, S_i, and Y_t). My main variables of interest are $Horizontal_{it}$, which indicates the number of horizontal wells within a mile drilled prior to the property's sale; and the interactions of the variable $Horizontal_{it}$ with the variable $Private_i$, which indicates whether the property is located outside the public water system and therefore likely relies on private well water for drinking water, and the variable $Violations_t$, which indicates the number of shale well violations in the county over the six-month period prior to each property's sale. Hence, I estimate the semilogarithmic form of the hedonic price function, expressed as follows:

$$\begin{aligned}\ln P_{it} = \alpha &+ \beta_1 Horizontal_{it} + \beta_2 Private_i + \beta_3 Violations_t \\ &+ \theta_1 (Horizontal_{it} \times Private_i) \\ &+ \theta_2 (Horizontal_{it} \times Violations_t) + X'_i \delta_1 + N'_i \delta_2 \\ &+ C_i + S_i + Y_t + + \varepsilon_{it}\,.\end{aligned} \tag{1}$$

The coefficient on the first interaction term, θ_1, measures the price discount associated with an additional horizontal well for a property that relies on private water. I hypothesize that θ_1 will be negative. The coefficient on the second interaction term, θ_2, estimates the effect of additional information on well violations for a property with a nearby horizontal well. I also hypothesize that θ_2 will be negative. In addition, I include a variable for the number of vertical wells within a mile of each property and estimate any interaction effects with vertical wells in all specifications. In robustness checks, I test various assumptions of this specification and offer an alternative nearest-neighbor matching estimation strategy.

Empirical Results

Estimates of the Cross-Sectional Hedonic Model

Table 2 summarizes my main results on the effect of an additional horizontal or vertical well that is drilled within a mile of the property prior to the property's sale. In equation 1, I do not control for any environmental disamenities, and I find that an additional well has no statistically significant effect on property values. In equations 2 and 3, I separately control for properties affected by two categories of risks: groundwater risks for properties that rely on private water wells (equation 2) and violations information (equation 3), and I find negative property-value effects for relevant properties with nearby horizontal wells. The separate inclusion of these variables also increases the coefficient on horizontal wells, which becomes statistically significant in equation 3, without affecting the estimated coefficients on other variables.

After controlling for both risks to water and violations information in equation 4, I find that an additional horizontal well within one mile increases a property's value by about 2 percent. Given the average price of homes in Washington County, this result suggests a price increase of a little more than $3,200 per additional well. I do not find any statistically significant effects on property values of an additional vertical well within one mile. The gains for additional horizontal wells represent the average effect of rental or royalty payments that accrue to some properties located within a mile of the well. In reality, properties that receive rental or royalty payments may have higher property-value increases while properties that do not receive rental or royalty payments might have no property-value increases or may face some losses.[19] While operators of vertical wells also pay royalty and rental payments to nearby property owners, the reach of vertical wells is not nearly as far, and fewer properties within a mile of these wells accrue payments.

Although an additional horizontal well increases a property's value by 2 percent, I find that a property that relies on private water wells loses on average 1.4 percent of its value with each additional horizontal well. Thus, properties that rely on private water wells only obtain a 0.6 percent average increase in property values per additional horizontal well. This result is consistent with the idea that individuals worry about water security for properties that rely on private water wells. Unlike Muehlenbachs, Spiller, and Timmins (2012), who also analyzed differential effects of nearby wells on piped versus well-water properties, I do not find that losses due to perceived water risks offset the property-value gains of an additional well on average. As before, I only find statistically significant effects for horizontal wells, suggesting that individuals are not as concerned about water risks from nearby vertical wells.

Finally, I find that properties with horizontal wells also lose value as the number of recent county-level shale well violations increase in the six months prior to each property's sale.[20] Specifically, for properties within one mile of a horizontal well, each additional EH&S shale well violation in the six-month period prior to the property's sale decreases the property's value by about 0.04 percent. Although this effect seems small, it can become substantial when considering the number of violations and the number of properties affected. Calculated at the average number of EH&S shale violations, each

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[19] In future work, I hope to differentiate between properties that receive rental or royalty payments and properties that do not. No one has done this to date.

[20] In Appendix A, I limit the violations time period to the three months prior to each property's sale; the qualitative results do not change.

additional horizontal well is associated with a 0.5 percent decrease in property values, decreasing the net effect of an additional horizontal well to about 1.5 percent. If the property also relies on private well water, then almost all of the gains of an additional well are offset by individuals' subjective risk perceptions.[21]

Table 3 presents results for information on all EH&S violations (equation 1) and then divides these violations into EH&S violations at shale wells versus those at conventional wells (equation 2). These results demonstrate that EH&S violations only have statistically significant effects on property values for properties with nearby horizontal wells, which is consistent with the idea that individuals seek out violations information when faced with the uncertain risks of a nearby horizontal well. Equation 2 also demonstrates that this result is driven by EH&S violations at shale wells—that is, individuals with nearby horizontal wells with uncertain risks seem to seek out information on EH&S violations that accrue to those types of wells in particular. Information on EH&S violations on conventional, typically vertical, wells has no property-value effect for properties with nearby wells, horizontal or vertical. Thus, these results suggest that individuals only update their subjective probabilities of the risks of horizontal wells using information on violations at shale wells—not information on violations at other wells.[22]

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[21] In these main specifications, I present results for the effect of wells located within a mile of each property, but in robustness checks, I show that the coefficients to be largest in magnitude when I use well counts within 0.75 miles of each property and especially for wells drilled within the year prior to the property's sale. This suggests that closer and more recent activity matters more for property values. These and other robustness checks are summarized in Appendix A.

[22] In Appendix A, I also consider the effect of well investigations, which should not provide much risk information to residents. I find that well investigations have no statistically significant effects on properties with nearby wells. In future work, I hope to provide a closer match between nearby wells and specific violations.

Overall, the estimated effects seem modest but may become large in some circumstances, especially considering the number of potentially affected properties. Table 4 provides a summary of estimated effects. For simplicity, the value of a property that has its water piped from the public water supplier is standardized at \$100,000. Because I estimate properties with private water wells to be worth more on average after I control for various property and neighborhood characteristics, those properties begin with a value of \$113,430.[23] Already, at the average number of EH&S violations, all the benefits of a nearby horizontal well are offset for properties that rely on private water, while properties with piped water retain modest net benefits. As the number of violations increase toward the maximum observed in my sample, all properties face net losses from an additional nearby horizontal well. Of course, properties that receive royalty payments from well operators may still see net benefits, but those that do not almost certainly face greater losses.

Nearest-Neighbor Matching Estimation

Another concern when estimating the effects of nearby wells is possible endogeneity or reverse causality because well placements are not random; operators choose where to drill and, in particular, may choose to drill where property values (and therefore leases) are cheaper. Then, instead of finding the effect of nearby wells on property values, I might pick up how property values influence an operator's decision to

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[23] I report the correct interpretation of the coefficient on the private-well indicator variable in the discussion. In a semi-log econometric specification, the correct interpretation of the coefficient is calculated using the following equation: $(e^{\beta} - 1) * 100$ percent, where β is the coefficient on an indicator variable, as pointed out in the literature (Halvorsen and Palmquist 1980; Kennedy 1981).

drill.[24] In this chapter, I find a positive and statistically significant effect of nearby horizontal wells on property values after I control for variables that are affected by risk perceptions. Although operators are not likely to have chosen to drill in locations where property values are higher, there is the possibility that the operators' strategic choices lead me to underestimate the positive effects of nearby wells.[25] In this section, I try to account for this possibility by employing an alternative estimation strategy: nearest-neighbor matching.

The goal of the nearest-neighbor matching strategy is to identify untreated properties that are similar to treated properties and thereby construct a control group. The effect of the treatment is then found by averaging across the price differences for matched pairs. This estimation strategy requires the use of an indicator variable that denotes the treatment, so I test the effect of at least one horizontal well within a mile for different types of properties or the effect of a risk-relevant feature for properties with and without at least one nearby horizontal well. The nearest-neighbor matching estimator allows me to require exact matches on certain dimensions, so I require that the matched untreated properties are located in the same school district. I then match on the sale year, the number of nearby vertical wells, and various property characteristics. I also take advantage of a bias-correction procedure that adjusts the difference within matches for

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[24] In Appendix A, I present results of a falsification test that suggest that my control variables mitigate this concern.

[25] There are other ways in which I might be underestimating the positive property-value effects of nearby wells. I don't know which properties actually receive royalty payments, so my coefficients represent the average effects for all nearby properties—those that receive rental and royalty payments as well as those that do not. In addition, the "control" properties that do not have nearby wells may soon have nearby wells and may already be receiving rental payments that raise their property value. Previous studies have also been unable to control for these effects (Muehlenbachs, Spiller, and Timmins 2012; Gopalakrishnan and Klaiber 2014).

observed differences in my matching variables as well as tract characteristics for matched properties. I require three matches for each treated property.

In Table 5 and Table 6, I present these results. In Table 5, I find that having at least one nearby horizontal well increases property values by about 8 to 10 percent, which is similar to my ordinary least squares regression results when I use a well indicator variable.[26] These gains, however, only accrue to properties connected to the public water system. Properties that rely on private water wells have no statistically significant gain or loss from having at least one horizontal well; in other words, these properties lose the 8 to 10 percent gain in property values that other properties tend to accrue with at least one nearby horizontal well but do not necessarily face further losses on average. I also flip the treatment by examining the property value effects associated with reliance on private water wells when matched to similar properties with and without at least one nearby horizontal well. Whereas reliance on a private water well is not associated with any statistically significant difference in property values for similar properties without a nearby horizontal well, reliance on private water wells is associated with a 38 percent decrease in property values for similar properties with at least one nearby well.

In Table 6, I use the matching estimator to validate my results on the effect of EH&S shale violations. This is difficult because I rely on the continuous nature of the violations variable, which captures the number of relevant well violations in the six months prior to each property's sale. I employ two treatments: having at least one nearby

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[26] In my dataset, properties that have at least one horizontal well have, on average, five such wells. Because of this, the indicator variables tend to show larger effects because they are not just showing the effect of an additional horizontal well—but rather, the effect of five horizontal wells. Multiplying my finding of a 2 percent increase for each additional horizontal well by five generates similar results. Results using indicator variables are presented in Appendix A.

horizontal well and having an above-average number of recent EH&S shale violations (as compared to the county's average level of such violations in my sample), and I split the properties into groups. I find two statistically significant results: all properties following an above-average number of recent EH&S shale violations sold for about 9 percent less, but those properties with at least one nearby horizontal well sold for about 17 percent less. The results using nearest-neighbor matching are consistent with my main results and suggest that site endogeneity is not a concern.

Conclusion

In this chapter, I analyze the property-value effects of nearby shale development in Washington County, Pennsylvania using a hedonic pricing model. Specifically, I analyze whether property sales data reveal evidence that buyers and sellers are responding to perceived risks of shale development. I find that most effects are driven by nearby horizontal wells, not by nearby vertical wells. After controlling for risks to water and information on violations, an additional horizontal well within a mile of a property increases the property's value by about 2 percent. Properties that receive water from a private water well, however, face property-value losses from nearby horizontal wells, but I find that, on average, these losses tend not to outweigh the value of an additional nearby well. In addition, I find evidence that individuals consider the number of recent EH&S violations on shale wells when assessing the risk of nearby horizontal wells. In particular, my main specification suggests that each violation decreases the value of a property with at least one horizontal well within a mile by about 0.04 percent. A nearest-neighbor matching estimation strategy supports my main results.

In general, my results suggest that individuals are aware of horizontal well risks. Individuals pay a premium to own a property that is connected to the public water system, and they pay less for properties with nearby horizontal wells when there have been a lot of recent well violations. The well-violation results are consistent with a model in which individuals rationally update their subjective risk probabilities of shale development using the information contained in well violations. Increased notifications about these violations could lead to even larger effects on property values, possibly outweighing the financial benefits.[27]

To put the risk results into perspective, I estimate the fatality risk probability implied by my risk coefficients. For example, I estimate that individuals are willing to pay 1.4 percent of a property's value, or $2,260 at the average house price, in order to avoid the risk of an additional nearby horizontal well when the property relies on a private well water. If the value of a statistical life is measured at $9 million,[28] then the implied risk would be equivalent to a fatality risk of 2.5 out of 10,000. Similarly, the implied fatality risk per recent EH&S well violation would be about 7.3 in 1,000,000 and the implied fatality risk at the average number of well violations would be about 1.3 in 10,000. Under the Superfund program, the U.S. Environmental Protection Agency generally acts to clean up a hazardous site when the cumulative lifetime excess cancer risk exceeds 1 in 10,000, and it has discretion to act when the cancer risk is measured to

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[27] Already, many Pennsylvania residents complain that they do not receive adequate information about the violations incurred by operators drilling near their properties. Erica Fink. 2012. "Reporting of Fracking and Drilling Violations Weak." *CNN Money*, May 1.

[28] This is a reasonable estimate based on the latest research using accurate fatality data (Viscusi 2013).

be between 1 in 1,000,000 and 1 in 10,000 (U.S. Environmental Protection Agency 1991). By this metric, individuals' implied risk perceptions for private well-water risks and general adverse well-event risks are roughly equivalent to the actual cancer risk associated with a high-priority Superfund site.

In Pennsylvania, Act 13 distinguishes between conventional and shale wells, applying more stringent statutory requirements for shale wells in order to manage their specific risks. Operators of shale wells may be subject to presumptive liability for water contamination, may be assessed impact fees by local governments, and must comply with larger setback rules and more extensive reporting and notification requirements. My results support Pennsylvania Act 13's application of more stringent requirements on operators of shale wells, although these additional requirements have not eliminated residents' concerns. Environmental groups have previously reported that PADEP's inspection and enforcement practices still leave much to be desired (Earthworks 2012).

Along those lines, my results underscore the need to develop comprehensive risk-management schemes and provide relevant, science-based information on risks to communities facing shale development. In Chapter III of this dissertation, I propose regulatory interventions to help manage water-contamination risks of nearby drilling, such as insurance mandates to ensure funds for compensation and remediation and additional tort and regulatory clarifications. Together, these interventions would create a risk-management scheme that could alleviate water-contamination property-value losses. Otherwise, as I demonstrate in Chapter II, local governments may turn to extreme solutions such as outright bans on natural gas extraction to bluntly prevent environmental damage and resulting property-value losses in their communities, thereby limiting access to potentially valuable natural resources.

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Tables

Table 1. Summary Statistics – Washington County, Pennsylvania.

Variables	Mean	Std. Dev.
Property Characteristics		
Sale Price (in year 2012 dollars)	161,344	145,144
Bedrooms (number)	3.08	0.89
Bathrooms (number)	2.05	1.01
Building Age	49.40	40.77
Total Living Area (1,000 square feet)	1.83	0.83
Lot Size (100,000 square feet)	0.28	1.19
Building Sold in Year Built	0.13	0.34
Stories (number)	1.82	0.75
Garage (0/1)	0.75	0.44
Fireplace (0/1)	0.29	0.45
Pool (0/1)	0.03	0.16
Private Well Water	0.08	0.27
Distance to Pittsburgh (miles)	18.93	7.74
Census Tract Characteristics		
Median Household Income	58,868	22,995
Mean Household Income	70,941	26,225
% Age 25+ w/ High School Degree	37.95	12.25
% Age 25+ w/ Bachelor's Degree	18.33	8.50
% Unemployed	6.95	3.30
% Poverty	9.66	7.92
% Over 65 Years Old	17.24	4.54
% Under 19 Years Old	24.33	4.72
% Black	4.32	7.32
% Latino	1.11	1.21
Shale Well Proximity		
Distance to closest well (miles)	0.63	0.87
Number of wells within 1 mile	4.93	5.81
Distance to closest horizontal well	2.06	2.51
Number of horizontal wells within 1 mile	0.17	1.18
Shale Well Compliance		
Well investigations in county, 6 months before sale	298.04	286.29
Violations in county, 6 months before sale	31.26	31.54
Environmental, health, and safety (EH&S) violations in county, 6 months before sale	18.88	21.41
EH&S shale violations in county, 6 months before sale	11.43	13.50

Table 2. Main Cross-Sectional Regression Results for Washington County.

	Natural Log of Sale Price (2012$)			
Variables	(1)	(2)	(3)	(4)
Vertical wells w/in 1 mile	0.001	0.003	0.002	0.003
(Vertical wells)	(0.003)	(0.004)	(0.003)	(0.004)
Horizontal wells w/in 1 mile	0.005	0.010	0.015*	0.020**
(Horizontal wells)	(0.006)	(0.007)	(0.008)	(0.010)
Vertical wells x Private well		-0.005		-0.005
water		(0.004)		(0.004)
Horizontal wells x Private well		-0.014*		-0.014*
water		(0.008)		(0.008)
EH&S shale violations			0.001	0.001
			(0.001)	(0.001)
Vertical wells x EH&S shale			-2.7e-5	-2.4e-5
violations			(5.3e-5)	(5.3e-5)
Horizontal wells x EH&S shale			-4.3e-4***	-4.3e-4**
violations			(1.5e-4)	(1.7e-4)
Private well water	0.089*	0.126**	0.090*	0.126**
	(0.047)	(0.055)	(0.047)	(0.055)
Building Age	-0.009***	-0.009***	-0.009***	-0.009***
	(4.7e-4)	(4.7e-4)	(4.7e-4)	(4.7e-4)
Total Living Area (1,000 sqft)	0.267***	0.266***	0.266***	0.266***
	(0.019)	(0.019)	(0.019)	(0.019)
Bedrooms (number)	0.027**	0.027**	0.027**	0.027**
	(0.011)	(0.011)	(0.011)	(0.011)
Bathrooms (number)	0.030***	0.030***	0.030***	0.030***
	(0.011)	(0.011)	(0.011)	(0.011)
Building Sold in Year Built	-0.381***	-0.382***	-0.381***	-0.382***
	(0.056)	(0.056)	(0.056)	(0.056)
Lot Size (100,000 sqft)	0.027***	0.027***	0.027***	0.027***
	(0.009)	(0.009)	(0.009)	(0.009)
Garage (0/1)	0.377***	0.377***	0.377***	0.377***
	(0.018)	(0.018)	(0.018)	(0.018)
Fireplace (0/1)	0.219***	0.219***	0.219***	0.219***
	(0.013)	(0.013)	(0.013)	(0.013)
Distance to Pittsburgh (miles)	-0.006	-0.008	-0.006	-0.008
	(0.011)	(0.011)	(0.011)	(0.011)
Median Household Income	0.003*	0.003*	0.003*	0.003*
	(0.002)	(0.002)	(0.002)	(0.002)
% Black	0.005	0.005	0.005	0.005
	(0.003)	(0.003)	(0.003)	(0.003)
% Age 25+ w/ High School	-0.011***	-0.011***	-0.011***	-0.011***
Degree	(0.004)	(0.004)	(0.004)	(0.004)
% Unemployed	-0.010	-0.011	-0.010	-0.011
	(0.009)	(0.009)	(0.009)	(0.009)

	Natural Log of Sale Price (2012$)			
Variables	(1)	(2)	(3)	(4)
% Under 19 Years Old	-0.016*	-0.016*	-0.016*	-0.016*
	(0.008)	(0.008)	(0.008)	(0.008)
Year Controls	Yes	Yes	Yes	Yes
City Controls	Yes	Yes	Yes	Yes
School District Controls	Yes	Yes	Yes	Yes
Constant	11.187***	11.231***	11.681***	11.692***
	(0.250)	(0.254)	(0.383)	(0.372)
Observations	21,987	21,987	21,987	21,987
Adjusted R-squared	0.613	0.613	0.613	0.613

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicators for property or tract characteristics are included in all regressions. *** p<0.01, ** p<0.05, * p<0.1.

Table 3. Shale Versus Conventional Environmental, Health, and Safety Violations.

	Natural Log of Sale Price (2012$)	
Variables	(1)	(2)
Vertical wells	0.003	0.003
	(0.004)	(0.004)
Horizontal wells	0.020**	0.019*
	(0.010)	(0.010)
Vertical wells x Private well water	-0.005	-0.005
	(0.004)	(0.004)
Horizontal wells x Private well water	-0.014*	-0.014
	(0.008)	(0.008)
EH&S violations	0.001	
	(0.001)	
Vertical wells x EH&S violations	-8.0e-6	
	(5.3e-5)	
Horizontal wells x EH&S violations	-4.1e-4**	
	(1.7e-4)	
EH&S shale violations		-1.8e-4
		(0.001)
Vertical wells x EH&S shale violations		2.7e-5
		(8.0e-5)
Horizontal wells x EH&S shale violations		-4.0e-4*
		(2.0e-4)
EH&S conventional violations		0.002*
		(0.001)
Vertical wells x EH&S conventional violations		1.2e-5
		(7.7e-5)
Horizontal wells x EH&S conventional violations		3.2e-5
		(0.001)
Private well water	0.126**	0.126**
	(0.055)	(0.055)
Property Characteristics	Yes	Yes
Census Tract Characteristics	Yes	Yes
Year, City, & School District Controls	Yes	Yes
Constant	11.710***	11.721***
	(0.372)	(0.370)
Observations	21,987	21,987
Adjusted R-squared	0.613	0.613

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicators for property or tract characteristics are included in all regressions. Property and census tract characteristics include the variables presented in Table 2. *** p<0.01, ** p<0.05, * p<0.1.

Table 4. Summary of Main Estimated Effects, Washington County.

	Property with Piped Water	Property with a Private Well
Additional horizontal well	102,000	114,030
Well plus average EH&S shale violations	101,510	113,540
Well plus max EH&S shale violations	99,940	111,960
Well plus average EH&S violations	101,230	113,260
Well plus max EH&S violations	98,390	110,420

Notes. For simplicity, the value of a piped property is standardized at $100,000.

Table 5. Matching Estimator, Water-Contamination Risk of Horizontal Wells.

	Natural Log of Sale Price (2012$)	
Sample	Well Treatment	Water Treatment
All Properties (*n*=22,002)		
Well treatment: 96.99 percent exact matches	0.098**	
	(0.040)	
Water treatment: 92.83 percent exact matches		0.027
		(0.043)
Properties with piped, public water	0.082**	
(*n*=20,306; 97.73 percent exact matches)	(0.044)	
Properties with private water wells	-0.013	
(*n*=1,696; 99.9 percent exact matches)	(0.077)	
Properties without a nearby horizontal well		0.070
(*n*=21,283; 92.14 percent exact matches)		(0.046)
Properties with at least one nearby horizontal well		-0.329***
(*n*=719; 92.92 percent exact matches)		(0.113)
Exact Matching Variable: School district	Yes	Yes
Other Matching Variables		
Number of vertical wells within a mile	Yes	Yes
Property characteristics	Yes	Yes
Sale year	Yes	Yes
Bias Adjustment Variables		
Matching variables	Yes	Yes
Tract characteristics	Yes	Yes

Notes. Robust standard errors. Each treated property is matched with three properties in the control sample. Well Treatment refers to having at least one horizontal well within a mile. Water Treatment refers to relying on a private water well. Exact match required on school district. Matching is also based on and the number of vertical wells within a mile, the sale year, and property characteristics that include building age, total living area, the number of bedrooms and bathrooms, the lot size, and the distance to Pittsburgh. Bias adjustment contains the property characteristics and tract characteristics that include the median household income, percent Black, percent age twenty-five with a high school degree, percent unemployed, and percent under nineteen years old. *** p<0.01, ** p<0.05, * p<0.1.

Table 6. Matching Estimator, Information on Violations.

Sample	Natural Log of Sale Price (2012$)	
	Well Treatment	Violations Treatment
All Properties (*n*=22,002)		
Well treatment: 96.99 percent exact matches	0.098** (0.040)	
Violations treatment: 98.02 percent exact matches		-0.086*** (0.017)
Properties sold when low EH&S shale violations (*n*=13,512; 88.08 percent exact matches)	0.016 (0.072)	
Properties sold when high EH&S shale violations (*n*=8,490; 96.86 percent exact matches)	0.057 (0.051)	
Properties without a nearby horizontal well (*n*=21,283; 97.84 percent exact matches)		-0.091*** (0.019)
Properties with at least one nearby horizontal well (*n*=719; 95.74 percent exact matches)		-0.157** (0.062)
Exact Matching Variable: School district	Yes	Yes
Other Matching Variables		
Number of vertical wells within a mile	Yes	Yes
Number of recent well investigations	Yes	Yes
Property characteristics	Yes	Yes
Sale year	Yes	Yes
Bias Adjustment Variables		
Matching variables	Yes	Yes
Tract characteristics	Yes	Yes

Notes. Each treated property is matched with three properties in the control sample. Well Treatment refers to having at least one horizontal well within a mile. Violations Treatment refers to having above-average EH&S shale violations in the prior six months. Exact match required on school district. Matching is also based on the number of vertical wells within a mile, the number of well investigations in the six months prior to the sale, the sale year, and property characteristics that include building age, total living area, the number of bedrooms and bathrooms, the lot size, and the distance to Pittsburgh. Bias adjustment contains the matching variables and tract characteristics that include the median household income, percent Black, percent age twenty-five with a high school degree, percent unemployed, and percent under nineteen years old. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

CHAPTER II

AN EMPIRICAL INVESTIGATION INTO THE LOCAL DECISION TO PROHIBIT SHALE DEVELOPMENT

Introduction

In 2012, the International Energy Agency (IEA) warned firms to support regulations that deal convincingly with environmental risks of high-volume hydraulic fracturing (fracking) and horizontal drilling, which would raise production costs by about seven percent, or else face widespread bans and other limits that would ultimately prove more expensive. Already, numerous cities and towns across the United States have started to prohibit all natural gas extraction activities, hindering a national energy policy that relies on continued increases in natural gas production (Cheren 2014). The IEA's statement, however, assumes that banning behavior would decrease in light of more stringent regulations—or at the very least, it assumes that banning behavior is motivated by the perceived environmental costs of shale development. Yet, no one has studied this question. In this chapter, I empirically investigate why some towns in New York chose to prohibit fracking either permanently (a ban) or for a specified term (a moratorium).

Although shale development provides economic benefits to communities, the extensive fracking associated with shale development also generates negative externalities that can range in severity from increased traffic and noise to potential groundwater contamination and other environmental damage.[29] These perceived costs

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[29] Appendix C provides a more detailed overview of some of these risks.

have made fracking highly controversial, especially in the state of New York. Since July 2008, New York has had a moratorium on high-volume fracking in order to allow the state to study the environmental effects of these drilling techniques and to develop appropriate regulations. In the meantime, more than fifty towns have passed fracking bans, and more than one hundred and twenty towns have passed moratoria on fracking activities. Thus, the events in New York provide an opportunity to analyze the fundamental drivers of these local decisions.

In this chapter, I develop a model wherein town board members decide whether to adopt a ban or a moratorium on fracking. Town board members take into account resident voter preferences, which are based on the net benefits of fracking, among other things. Previous work has found that voter preferences are important determinants of state-level smoking restrictions (Hersch, Del Rossi, and Viscusi 2004). In this study, I model how residents are likely to form their preferences and use insights from the model to inform my empirical specification. I then combine various sources of town-level and county-level data to analyze and explain the town's decision to ban or delay fracking.

Overall, I find evidence that water-risk concerns play an important role in the decision to adopt a ban. Towns with a higher reliance on private water wells and those with higher livestock water use are associated with a higher probability of adopting a ban. In addition, towns with more Black residents and with a greater reliance on private water wells are particularly likely to ban shale development, possibly due to African Americans' higher likelihood of living in areas with poor water quality (U.S. Department of Housing and Urban Development 2011). Demographic characteristics, environmental preferences, and political interests also predict whether a town will adopt a ban.

Moratoria adoption, on the other hand, is different. Towns with higher water risks and with greater drilling experience are less likely to adopt a moratorium. The largest driver of moratoria adoption is the county recycling rate, possibly because moratoria are mostly symbolic gestures given the state moratorium on fracking activities. As symbolic gestures, it is not surprising that moratoria are adopted where residents have strong environmental preferences but are not adopted where residents might have real concerns about water risks. Finally, industry presence and previous experience with drilling tend to decrease the probability that a town adopts any anti-fracking measure.

Literature

This research draws on public choice models of policymaking by state and local governments. In these models, the preferences of voters are important because they affect the incentives of policymakers to support various laws and regulations. These models are often augmented with nonvoter factors, such as political pressures from interest groups.

My analysis most closely resembles the work of Hersch, Del Rossi, and Viscusi (2004), who analyzed how voter preferences influence the probability that a state has a smoking restriction.[30] Their model was based on the median voter theory of government action (Black 1948; Downs 1957). Essentially, when there are two political candidates vying for a position, the median voter theory posits that a majority-rule voting system will select the candidate most preferred by the median voter, and political candidates will maximize their support when they gravitate toward the median voter's position (subject

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[30] Hersch, Del Rossi, and Viscusi's (2004) examination of determinants of state smoking restrictions has already been extended to local smoking restrictions using methodology similar to that used in this chapter (Phelps 2012).

to a number of simplifying assumptions). At its core, the model predicts which voter preferences are important to candidates or incumbents seeking to maintain their office. The model says nothing about how voters form their preferences but does assume that voters behave rationally and consistently based on their ordered preferences. Thus, economists and political scientists have invoked the median voter model as a way to use the individual utility maximizing model applied to the median income family to analyze government behavior.

The median voter model, however, rests on a special set of assumptions about group preferences that may not be satisfied in practice (Stearns and Zywicki 2009). In most elections, for example, there are more than two candidates; policy preferences rarely align along a single-dimensional scale; and the voting population is divided into electoral districts. In those cases, it is still possible for self-interested political candidates to converge on the median voter's position, but other outcomes are also possible, often depending on the voting scheme. In New York, the town board serves as the governing board of each town and is typically made up of five elected officials—the supervisor (two-year term) and four councilpersons (four-year terms). Most towns employ at-large majority voting to elect the single supervisor every two years, but use at-large single-nontransferable voting to elect two councilpersons every two years (a plurality voting system).[31] Theoretically speaking, the outcome from a plurality-voting system need not coincide with the median voter outcome (Stearns and Zywicki 2009), meaning that the councilpersons need not converge on the median voter's preferences to get elected.

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[31] Thirteen towns, however, employ a ward election system instead of an at-large election system. Appendix B presents the main results with the inclusion of a control for these towns. The qualitative results remain the same.

Nonetheless, there are reasons to think that the median voter model has motivational relevance in this context as a way to summarize voter preferences. First, the elected official has an obligation to represent resident preferences in New York. According to the New York town manual, whenever a town councilperson votes on a proposal before a town board, "he or she is representing, through that vote, the views of all of the residents of the town."[32] Even for self-interested local politicians, voter preferences on shale development are important because the politicians may fear retaliation from voters in the next election, retaliation that is more likely on a local scale where the anti-fracking action may be one of few town board actions. Resident homeowners pay particular attention to decisions that affect the use of their land, and those local decisions are especially likely to be majoritarian (Serkin 2006). Local politicians are also likely to know resident preferences in this context, usually having held town resident meetings in advance of any anti-fracking action. In short, local officials fulfill their duties and often maximize their support when they estimate and follow resident preferences when making a decision on a proposal.

In this work, I explore the determinants of residents' preferences that can affect a politician's perception of the median voter's position in his community. I assume that residents are rational and that they choose the position on a proposed action that maximizes their expected utility based on their perceptions of the costs and benefits of the proposed action. Of course, the public choice literature is also concerned with how citizens translate preferences into voting behavior—and why they vote at all.[33] In my

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[32] Association of Towns of the State of New York, Town Law Manual for Town Supervisors and Town Boards, http://townverona.org/content/Laws/View/7:field=documents;/content/Documents/File/35.pdf.

[33] Because any one person's vote is unlikely to drive the outcome of an election, the act of casting a vote is considered to be not worth the effort in most cases.

model, politicians assume that residents get additional benefits from expressing their preferred outcome in the form of voting. Politicians are also aware of the various demographic factors that could lead some residents to be more or less likely to express their preferences or engage in collective action.[34]

When forming preferences, I assume that residents weigh the benefits and costs of fracking activities in their town. For bans, which are mostly enacted through local zoning amendments, this assumption is reasonable as zoning has been long thought to be a way for local governments to manage various industry externalities and protect property values. As I show in Chapter I, perceived water-contamination risks can lower some property values; residents vulnerable to water contamination in New York towns may fear these risks and property-value losses. Moratoria are often enacted as local ordinances, and the moratoria are unlikely to have much effect given the state's longstanding moratorium on fracking activities and the short adopted duration of most town moratoria. Residents considering temporary moratoria may not weigh the costs and benefits of fracking in the same way as are residents considering bans. Hence, the drivers of these two anti-fracking actions are likely to be different.

Scholars have analyzed mechanisms aside from the median-voter model that influence the legislative preferences of politicians. One prominent alternative theory is the interest group theory (Stigler 1971; Peltzman 1976; Becker 1983), which posits that rational legislators are likely to confer regulatory benefits on interest-seeking industry groups. Although I do not explicitly rely on this model, I use insights from it, such as the idea that the presence of an industry in an area could translate to political influence. In

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[34] My assumptions about how politicians estimate resident preferences are similar to those in Hamilton's (1995) analysis of how firms estimate the intensity of resident preferences in their decisions to locate in different neighborhoods.[34]

general, studies have found that both median voter models and interest group models are useful in explaining local and state spending (*e.g.*, Congleton and Bennett 1995; Ahmed and Greene 2000; Walden and Eryuruk 2012).

New York Anti-Fracking Actions and Preferences

In New York, the Department of Environmental Conservation (NYDEC) regulates oil-and-gas permitting and drilling activities.[35] Since July 2008, New York has had a moratorium on high-volume fracking in order to allow the NYDEC to study the environmental effects of the drilling techniques associated with fracking and to develop appropriate regulations. In furtherance of this goal, the NYDEC released a draft Supplemental Generic Environmental Impact Statement (draft SGEIS) in September 2009 and a revised draft SGEIS in September 2011.[36] Currently, the NYDEC is waiting on a review of the potential impacts of shale drilling on public health before it finalizes the SGEIS. Once completed, the final SGEIS will apply statewide, except in areas that the NYDEC determines will be off-limits to fracking, and the NYDEC will use its SGEIS findings to develop criteria and conditions for permit approvals.

Despite the regulatory uncertainty, oil-and-gas operators have shown interest in New York. Landowners in Chemung and Tioga counties in New York, for example, have already been receiving rental payments of about $500 per acre (Marcellus Drilling News

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[35] The Delaware River Basin Commission (DRBC) has power to oversee drilling in its area of jurisdiction, which includes parts of New York in the watershed area of the Delaware River. To date, the DRBC has indicated an interest in reviewing New York's drilling regulations before proposing any regulations.

[36] 2011. "Revised Draft SGEIS on the Oil, Gas and Solution Mining Regulatory Program." http://www.dec.ny.gov/energy/75370.html.

2012).[37] The NYDEC has also received applications for permits to drill horizontal wells while it works to finalize the new drilling rules.

Although the statewide moratorium has suspended fracking activities for the time being, both proponents and opponents of fracking have begun to think about the future of fracking in their communities. Below, I provide information on the anti-fracking town actions analyzed in this study and describe the results of recent polls on New York preferences on fracking.

New York Town Anti-Fracking Actions

Many New York town residents have voiced their concerns about fracking to their local town boards. New York has 932 towns, and each town is governed by a town board that may adopt local laws pursuant to the home rule powers granted by Article 9 of the State Constitution and the Municipal Home Rule Law. In many cases, these town boards have adopted fracking-related measures. Some town boards have adopted resolutions stating that the town will wait until the NYDEC issues regulations before making any decisions on fracking within the town's borders, a neutral action considered to be supportive of fracking. Other towns, however, have voted to prohibit fracking either permanently (a ban) or for a specified term, usually between six months and two years (a moratorium). This study analyzes the anti-fracking actions of these towns. Table 7

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[37] These payments are much lower than those in other states such as Pennsylvania and Ohio given the uncertainty surrounding eventual drilling authority in New York.

provides a list of the towns that adopted an anti-fracking measure between 2010 and 2013 that are included in this analysis.[38]

Most fracking bans have been amendments to (or new versions of) local zoning laws, adopted under the towns' home-rule authority. Typically, the towns enact language to clarify or reiterate that horizontal drilling and fracking in particular (*e.g.*, Camillus) or all natural gas activities generally (*e.g.*, Lumberland) are incompatible land uses in all zoning districts. In some cases, the town also lists reasons for its actions. For example, the town of Tusten explicitly writes that the law "is intended to protect drinking water supplies." One exception is the town of Wales, which enacted its ban as a rights-based ordinance instead of a zoning local law, asserting the right of the community to protect its environment from harmful activities. Specifically, the town cites "the inherent right of the residents of the Town of Wales to govern and protect their own community" as the authority for its ban and notes that the town "relies exclusively on the existence and usage of natural well water as its sole source of water." In Table 8, I provide detail on some of the language used by towns that banned fracking in 2010 or 2011. Towns that banned fracking in 2012 or 2013 used similar language.

I define anti-fracking moratoria as temporary bans on natural gas exploration, extraction, and production activities that range in duration from three months (Onondaga) to until proven safe (Westmoreland), although the most common duration is one year.[39] These moratoria are often extended or renewed, though some town boards have allowed moratoria to expire. The towns often explicitly note that the moratoria address matters of

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[38] In addition, there were six towns that adopted an anti-fracking measure during the sample period that were excluded from this analysis because the towns do not lie on a shale formation. Appendix B provides a list of these towns and also lists some cities and villages that adopted bans or moratoria.

[39] The adopted duration of 72 percent of moratoria was twelve months.

local concern and were enacted pursuant to the towns' home-rule authority. Many towns also cite environmental and, in particular, water concerns as reasons for adopting moratoria. For example, the town of Avon notes, that "[m]any residents are dependent upon aquifers and wells for life sustaining water [and] maintaining the quality of water resources within the Town is critical to protecting the natural environment of the Town, the general health and welfare of Town residents, and the local economy."[40] Twenty-seven towns that adopted a ban on fracking activities between 2010 and 2013 had previously adopted a moratorium on fracking.

Already, two towns, Dryden and Middlefield, are involved in litigation surrounding their actions banning fracking outright through zoning laws.[41] The town of Dryden was initially sued by the Anschutz Exploration Corporation, a privately held drilling company, while the town of Middlefield was sued by a landowner who had signed two oil and gas leases in 2007 with Elexco Land Services, Inc. The towns won their lawsuits at the lower-court level, with courts upholding the actions under the home-rule authority of the towns to engage in zoning. On appeal, Norse Energy, a Norway-based drilling company (whose U.S. unit filed for bankruptcy protection in December 2012) replaced Anschutz Exploration in the Dryden case. The New York Appellate Court upheld the lower-court decisions in May 2013.[42] In August 2013, New York's highest court, the Court of Appeals, agreed to hear the cases, which are being tried together. The Court's decision is pending. Meanwhile, town bans are not the only anti-fracking actions

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[40] "Moratorium on and Prohibition of Gas and Petroleum Exploration and Extraction Activities Underground Storage of Natural Gas and Disposal of Natural Gas or Petroleum Extraction Exploration and Production Wastes," Town of Avon Local Law No. T-A-5-2012.

[41] The initial lawsuits were Anschutz Exploration Corp. v. Town of Dryden, 940 N.Y.S.2d 458, 474 (N.Y. Sup. Ct. 2012); Cooperstown Holstein Corp. v. Town of Middlefield, 943 N.Y.S.2d 722, 724 (N.Y. Sup. Ct. 2012).

[42] Norse Energy Corp. USA v. Town of Dryden, 964 N.Y.S.2d 714 (N.Y. App. Div. 2013); Cooperstown Holstein Corp. v. Town of Middlefield, 964 N.Y.S.2d 431 (N.Y. App. Div. 2013).

being attacked in New York courts. A lower court in New York has also upheld against challenge the authority of a town to enact a moratorium.[43]

These decisions on the ability of towns to enact bans or moratoria on natural gas activities are likely to have a significant effect on shale development in New York. If the town actions are upheld, then operators will evaluate whether to invest in drilling in New York in light of the local regulatory uncertainty—that is, in light of the fact that a town board can ban drilling at any time.[44] In addition, it is unclear whether a future New York state law could strip towns of this authority, as Pennsylvania legislators recently discovered. In 2012, Pennsylvania's legislature passed a law known as Act 13 that, among other reforms, gave drilling operators the right to drill anywhere notwithstanding local zoning that might prohibit drilling in sensitive areas, such as residential areas.[45] The Supreme Court of Pennsylvania, Pennsylvania's highest court, found that part of Act 13 unconstitutional under Pennsylvania's Constitution.[46] Because local control could play an important role in the regulation of shale development in many states, it is important to understand what predicts banning behavior.

New York Opinions on Fracking

Although there is no poll that provides town-level preferences on fracking, there have been a few state-level polls on fracking views in New York. These polls tend to show New Yorkers divided on the issue, with typically a slight majority opposing the practice. One detailed 2011 poll of 941 adults found that statewide, 38 percent of adults

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[43] Lenape Resources, Inc. v. Town of Avon, Index No. 1060-2012 (N.Y. Sup.Ct. Mar. 15, 2013). This was the first court to successfully affirm a moratorium.

[44] The ability of towns to ban fracking could also be seen as a bargaining chip (Rose 2013).

[45] 58 Pa. Cons. Stat. §§ 2301-3504 (2013), which amends the Oil and Gas Act (Title 58).

[46] Robinson Twp., Washington Cnty. v. Com., 2013 WL 6687290 (Pa. Dec. 19, 2013).

supported fracking, 41 percent opposed it, and 21 percent were unsure.[47] Of those adults living in upstate New York, 37 percent supported fracking, 47 percent opposed it, and 16 percent were unsure. Overall, Democrats were most likely to oppose fracking, with about 47 percent opposing the practice. Republicans were most likely to support fracking, with about 49 percent supporting it. The relationship between fracking opposition and income was counterintuitive, with New Yorkers who made less than $50,000 being most likely to oppose fracking (at 43 percent, compared to 33 percent that support it), while those who made between $50,000 and $100,000 and those who made more than $100,000 were relatively split on the issue (with 44 and 42 percent, respectively, supporting it compared to 40 percent opposing it). Finally, men were more likely to support fracking (at 48 percent supporting it compared to 41 percent opposing it), while women and nonwhite respondents were more likely to oppose fracking (at 42 and 45 percent, respectively, opposing it compared to 29 and 34 percent, respectively, supporting it).

When the tradeoffs associated with shale development were made explicit, New Yorkers were similarly divided. When asked which was more important, “making us more independent from foreign oil” or “preserving water supplies and the environment,” 51 percent of New Yorkers living in upstate New York chose the environment, 45 percent chose energy independence, and 4 percent were unsure.[48] Similarly, when asked which is more important, “creating jobs” or “preserving water supplies and the

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[47] NY1/YNN-Marist Poll, May 17, 2011, Marist College Institute for Public Opinion. The question was worded as follows: “Hydraulic fracturing, often referred to as hydrofracking, is a process of splitting rocks underground to remove natural gas. From what you have read or heard, do you generally support or oppose hydrofracking?” The survey was conducted between April 25 and April 29, 2011, and participants were contacted by land line and through random dialing of cell phones.

[48] Specifically, the question was worded as follows: “Those who support this process say it makes us more independent from foreign oil and creates jobs. Those who oppose this process say it contaminates community water supplies and the environment. What do you think is more important: Making us more independent from foreign oil or preserving water supplies and the environment?”

environment," 52 percent of New Yorkers chose preserving the environment, 41 percent chose creating jobs, and 6 percent were unsure.[49] Though these data do not provide information on how resident preferences form and how they vary among towns, the data highlight which demographic characteristics might be relevant. The survey questions also emphasize the tradeoffs that are relevant for residents when they make their decisions: water supplies, the environment, energy independence, and jobs. Below, I present a theoretical framework that formalizes some of these tradeoffs.

Theoretical Framework

My analysis is framed by the following model of the relationship between a town board's decision to adopt a ban and my variables of interest. Let B_i be a binary indicator of whether the town board in town i adopts a fracking ban. The probability that town i has a fracking ban depends on b_i, a measure of preferences for a fracking ban by town residents, a vector X_i of demographic variables that capture additional preferences that might not be reflected by b_i, and a vector Z_i that represents the influence of interest groups and other political variables, summarized by the following equation:

$$\Pr(B_i = 1) = \rho(\,\alpha_1 b_i + X_i'\alpha_2 + Z_i'\alpha_3). \qquad (2)$$

In this model, I assume that the town board's decision to adopt a ban is responsive to resident preferences, b_i. Resident preferences are salient to local elected officials. Town boards typically adopt bans after receiving significant input from residents through

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[49] Specifically, the question was worded as follows: "Those who support this process say it makes us more independent from foreign oil and creates jobs. Those who oppose this process say it contaminates community water supplies and the environment. What do you think is more important: Creating jobs or preserving water supplies and the environment?" The preference breakdown for upstate residents was similar to the statewide preference breakdown on this question.

scheduled town hall meetings on the proposed actions. Resident preferences are also relevant because those town board members that do not adhere to resident preferences risk being voted out of office during the next local election.

So far, this model resembles the theoretical framework for Hersch, Del Rossi, and Viscusi's (2004) analysis of state smoking restrictions with the key exception that I do not have data on town voter preferences to directly estimate b_i. In my model, town board members estimate resident preferences by calculating the net benefits of a ban to the median voter. Hence, the probability of adopting a ban increases as resident preferences for a ban increase, and resident preferences for a ban increase as the expected environmental damages increase, the consumption value of voting for a ban increases, and the costs associated with organizing support for a ban decrease. Formally, resident support for a ban, b_i, is determined in the following way:

$$\mathrm{b}_i = \delta_1(e_i - r) + \delta_2 s_i + \delta_3 c_i + \varepsilon, \tag{3}$$

where e_i is the expected value of environmental and health damages, r is the expected rental or royalty payments, s_i is the satisfaction that the median voter derives from the ban, c_i is the transaction cost associated with supporting political action in the town, and ε is random error. An assortment of variables will be used to proxy for these dimensions that are broadly discussed in this model.

In particular, the expected value of environmental and health damages, e_i, depend on the perceived probability and extent of damages and on the value that residents place on such damages. Therefore, I expect e_i to depend, among other things, on the value of the town's water resources, which may become polluted; the proportion of residents who rely on private wells for consumption or for livestock, making residents and livestock more vulnerable to negative health effects of contamination;[50] the importance of agriculture to the local economy, an industry that might be affected by extensive drilling; and the proportion of environmentalists in the town. For simplicity, I model expected rental and royalty payments, r, to be a priori the same for each town. Rental and royalty payments offset some of the expected damages of fracking. This means that residents tend to support bans in towns where the perceived expected damages are higher than expected rental and royalty payments.

In addition, I expect town preferences to be a function of the satisfaction that town residents are likely to derive from the ban (s_i). Political scientists puzzled by the persistence of voting despite the low probability that any one person's vote matters have hypothesized that the consumption value of voting may be the most important driver of voting behavior. I hypothesize that towns with a high proportion of environmentalists, for example, are likely to have residents with a high consumption value of banning fracking.

Finally, board members are also likely to pay attention to c_i, or the cost associated with supporting political action in the town. As the cost of collective political action increases, then residents are less likely to actively support a ban—and less likely to vote councilpersons out of office for their actions. Residents who actively participate in political parties likely face lower costs of political action, while residents in towns with a large population face higher costs to collective action.

For the decision to enact a moratorium, town board members would also look to resident preferences. However, residents may be less likely to form their preferences for a moratorium by considering the benefits and costs of fracking activities simply because a

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[50] At least one study links cases of illness and death among farm animals and other wildlife to contamination from nearby shale development (Bamberger and Oswald 2012).

temporary moratorium is likely to expire before fracking becomes a possibility in New York given the state moratorium. Preferences for a moratorium may depend more on the environmental preferences of residents.

Data Description

To examine the motivations behind town anti-fracking actions, I constructed relevant variables from various state and local sources. These variables are summarized in Table 9. First, I only considered towns that likely lie upon the Utica or the Marcellus shale formations in order to focus on the towns with residents who would reasonably balance the competing costs and benefits of shale development because the probability of fracking is nonzero.[51] Because there is some uncertainty regarding the exact contours of the shale formations, I applied a simple decision rule: if a shale formation is known to underlie a part of a county, then I include all the towns in the county in my analysis.[52] This limited my analysis to 688 towns out of the 932 towns in New York.

Second, I created variables that indicated whether a town adopted a ban or a moratorium between 2010 and 2013. I used town websites, news articles, and pro-fracking/anti-fracking group websites to generate a list of all towns that adopted bans or moratoria through 2013; the year in which they first adopted the anti-fracking measure; and the adopted duration of any moratoria. The FracTracker Alliance, for example,

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[51] Towns that do not lie on a shale basin may still adopt fracking bans or moratoria, but the motivations for these actions are likely to be different, driven more by the consumption value of the action than by the expected costs and benefits of the action, for example. Appendix B provides a list of these towns.

[52] This decision rule excluded towns in the following counties: Clinton, Columbia, Dutchess, Essex, Franklin, Fulton, Hamilton, Nassau, Putnam, Rensselaer, Richmond, Rockland, Saratoga, St. Lawrence, Suffolk, Warren, Washington, Westchester, and New York City counties (Bronx, Kings, New York, and Queens).

provided an excellent starting point for much of my research.[53] I supplemented their lists of anti-fracking actions with original documents from the Food & Water Watch website[54] and town websites. Table 10 summarizes the types of actions that I identified per year.

For my analysis, I created separate variables for bans and moratoria because these actions were vastly different in scope and effect, especially in light of the state's moratorium on fracking. As discussed previously, the bans were mostly enacted through zoning amendments that would be difficult to repeal. The moratoria, in contrast, were temporary, and some were allowed to expire without renewal. The moratoria also varied greatly in duration. I include the first adoption of a moratorium in my study (regardless of whether the moratorium was renewed). According to Table 10, the number of towns adopting moratoria peaked in 2012 and declined in 2013. In addition, twenty-seven towns that adopted moratoria switched to a ban.[55]

Next, I generated variables to capture the value of clean water to each town's residents. As discussed previously and in Chapter I, the potential for water contamination is a high-priority issue in public fracking discussions. Water risks are especially important in both Pennsylvania and New York because so many residents rely on private well water.[56] To construct these variables, I collected county-level data from the U.S. Geological Survey on water use for the year 2005. These data contain estimates of the total population served by the public water supply in each county, and I used this

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[53] Current High Volume Horizontal Hydraulic Fracturing Drilling Bans and Moratoria in NY State, http://www.fractracker.org/map/ny-moratoria/. My research has led me to make a few changes to the initial categorizations of the FracTracker Alliance.

[54] Local Actions Against Fracking, http://www.foodandwaterwatch.org/water/fracking/fracking-action-center/local-action-documents/.

[55] In robustness checks contained in Appendix B, I separate bans and moratoria by adoption year and moratoria by duration.

[56] Pennsylvania has the second-highest number of households served by private water wells, and New York has the fourth-highest number of households served by private water wells. "Groundwater Supply and Use," http://wellowner.org/groundwater/groundwater-supply-use/.

information to construct a measure of the proportion of the population that relies on private water wells in each county. I also constructed estimates of the million gallons of water privately withdrawn from groundwater and surface water sources each day for livestock and crop irrigation use from these data.

I also created variables based on the number of domestic drinking water wells and agricultural wells drilled in each town since April 2000. I obtained these data from NYDEC, after submitting a FOIL (New York's Freedom of Information Law) request. I treated all wells categorized as iterations of "Domestic," "Drinking," or "Potable" as domestic water wells and summed these wells for each town. I treated all wells categorized as iterations of "Agricultural," "Farm," or "Irrigation" as agricultural or irrigation wells and summed these wells for each town. Although these data are not complete, they were the only town-level data on water-well reliance that I could find. I have no reason to suspect that the missing pre-2000 data would systematically affect town well totals in a way that is correlated with adopting fracking actions, but unfortunately the data contain many zero entries for towns. Nonetheless, I use the variables constructed from these data in robustness checks in conjunction with the county-level water-use data.

In addition, I generated variables that measure the history of drilling in each town using data from the NYDEC. I calculated the number of vertical, horizontal, oil, and gas wells in each town that had a drilling, completion, permit-application, or permit-issue date that was before January 1, 2010. Alternatively, these variables could approximate the presence and influence of industry groups in those towns.

I also approximated the proportion of active party members in each town's population using county-level voter registration data for November 2008 from the New York Board of Elections. A higher proportion of residents actively engaged in politics suggests an organized community that is more likely to engage in collective action. I separated active membership by the main political parties—Democratic and Republican—because preferences about fracking tend to vary by political party, as demonstrated in the previously discussed polling results. In particular, active Democrats are more likely to be attentive to environmental concerns associated with fracking. I combined the proportion of active Greens with the proportion of active Independents for each county. Although fracking preferences may vary for these two groups, the proportions even on the county level are too small to be meaningful.

In addition, I include an estimate of county-level recycling rates, as measured by a representative national survey administered by Knowledge Networks.[57] This variable would capture both environmental preferences and, because recycling rates are influenced by various state and local programs, the successful adoption of other environmentally favorable policies.

Finally, I match each town to various demographic characteristics from the American Community Survey (ACS). These characteristics include the median household income, the total population, the percent of the population under nineteen years old, the percent of the population that is Black, the percent of owner-occupied homes, the percent of the population twenty-five years and older that only completed high school, and the percent of the population twenty-five years and older that have more than a high school

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[57] The Knowledge Networks panel is based on probability sampling of both online and offline populations, providing the necessary hardware and Internet access if a respondent does not have access to a computer or the Internet. These data were purchased by Vanderbilt Law School.

degree. These data come from the ACS's five-year average estimates for 2006 to 2010, which provide town-level demographic characteristics before the adoption of the bans and moratoria in this study.

Empirical Specification

To test whether my empirical model predicts the adoption of a ban or a moratorium, I estimate the following cross-sectional equation based on observable data:

$$\Pr(B_i = 1) = \rho\big(Water_{i,j}'\alpha_1 + Drilling_i'\alpha_2 + Political_j'\alpha_3 + \alpha_4 Recycling_j + X_i'\alpha_5 + \varepsilon\big), \tag{4}$$

where the probability that town i in county j adopts a ban or a moratorium ($\Pr(B_i = 1)$) depends on a vector of measures of the town's vulnerability to risks to water ($Water_{i,j}$), a vector of variables representing the town's experience with oil-and-gas drilling and expectations for future drilling ($Drilling_i$), a vector of the proportion of the county's residents who are active members of relevant political parties ($Political_j$), the county recycling rate ($Recycling_j$), and a vector of town-level demographic characteristics (X_i).

Specifically, B_i is a binary variable equal to 1 if town i adopted a ban or, in other specifications, a moratorium. I use probit estimation and report marginal effects. I regress B_i on variables that proxy the relevant features of the town decision, based on my theoretical framework. The vector $Water_{i,j}$ includes variables that proxy the expected environmental and health costs of an adverse well event, particularly water-contamination risks, measured on either the county or the town level. This includes the proportion of county residents who rely on private water wells, the daily millions of gallons of water used in the county for livestock or crop irrigation, and the number of private water wells and agricultural or irrigation wells drilled in the town since April 2000. I expect the coefficients on these variables to be positive, denoting an increased probability of adopting a ban or a moratorium.

The next vector, $Drilling_i$, includes town-level variables such as the number of oil-and-gas wells drilled in the town prior to 2010 and the number of horizontal well applications on file with NYDEC prior to 2010. These variables show the history of oil-and-gas drilling in each town, and previous experience with oil-and-gas drilling could be related to residents' perceptions of the risks of shale development. In addition, the variables could approximate the presence and influence of industry groups in the area, directly contributing to Z_i in the model or indirectly affecting residents' risk perceptions and, therefore, their preferences. If so, then I expect the coefficients, summarized in vector α_3 to be negative—indicating a lower likelihood of adopting a ban.

Next, $Political_j$ is a vector of county-level variables that indicate the proportion of the county's residents who are active members of the Democratic, Republican, and other parties. These variables reflect both preferences and the ease of collective action. I expect the coefficient on the proportion of active Republicans to be negative while the coefficient on the proportion of active Democrats to be positive.

Finally, I include a vector of town-level demographic characteristics X_i, specifically the median household income, the town population, the percent of the population twenty-five years and older that graduated only high school, the percent twenty-five years and older that graduated with more than a high school degree, the percent under nineteen years old, and the percent that is Black, as well as the percent of owner-occupied homes in the town.

Empirical Results

In Table 11, I summarize the main results for the adoption of a ban. I find that expected water risks play a robust role in predicting the adoption of bans. In the decision to adopt a ban on fracking, towns in counties with a higher proportion of their population relying on private water wells and those in counties that use more water for livestock are associated with a statistically significant higher probability of adopting a ban. In equation 2, a higher number of private water wells and a higher number of agricultural wells in the town are also associated with a higher probability of adopting a ban. These results suggest that residents in these towns are more likely to perceive net costs of fracking.

Meanwhile, towns with previous oil-and-gas development and towns that anticipate operator interest in horizontal development are associated with a statistically significant lower probability of adopting a ban. These results suggest the role of experience in diminishing perceptions of expected environmental damages or the pro-fracking influence of industry in these towns.

In addition, organized preferences matter. Towns in counties with a higher proportion of Democrats are associated with a statistically significant higher probability of adopting a ban, while Republicans are associated with a statistically significant lower probability of adopting a ban. Towns in counties with high recycling rates are also more likely to ban fracking.

Finally, I find that demographic characteristics also predict ban enactment. In both equations 1 and 2, I find that towns with a higher percent of residents with only a high school degree are associated with a statistically significant lower probability of banning fracking, while towns with a higher percent of residents with more than a high school degree are associated with a statistically significant higher probability of adopting a ban. I also find that towns with a higher percent of young residents are also associated with a statistically lower probability of banning fracking. These results are likely driven by the relative attractiveness of oil-and-gas jobs to those who have only a high school degree. Most oil-and-gas jobs only require a high school degree (or equivalent), provide on-the-job training, and pay well.[58] There is already concern that high school graduates in shale-rich areas will forego college for lucrative oil-and-gas jobs.[59] Those with more education and those who are older, on the other hand, tend to have other employment options.

In addition, towns with a higher percent of owner-occupied homes are associated with a statistically significant higher probability of adopting a ban. Property owners may collect rental and royalty payments from oil-and-gas operators. When owners live elsewhere, they could reap the rewards of fracking activities without facing these costs. Those who also live on their properties, however, would have to tolerate the costs of shale development. In equation 2, I also find statistically significant and negative associations between median income and town population and the probability of adopting a ban. My results are consistent with New York polling data that indicates that support for fracking is higher among higher income groups. And, as the size of the town's

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[58] Sid Pranke. 2012. "Bakken Oilfield Jobs: Do You Have What It Takes?" *Bakken Today*, August 30.
[59] News Source. 2013. "Drilling or a College Diploma." *Shale Stuff*, May 14.

population increases, the ease of organizing against fracking decreases, making towns with large populations less likely to ban fracking.

Interestingly, I also find that towns with a higher percent of Black residents are associated with a statistically significant higher probability of adopting a ban. African Americans are more likely to be exposed to poor water quality (U.S. Department of Housing and Urban Development 2011), and they may have stronger concerns about the water-contamination risks of fracking activities. The New York polling data also revealed that nonwhite respondents were more likely to oppose fracking, and this opposition could be related to fears about further deterioration in water quality. For example, Viscusi, Huber, and Bell (2014) have previously documented that Black individuals are more likely than others to drink bottled water because they perceive bottled water to be safer.

To test whether the opposition of Black residents may be related to water-risk vulnerability, I interacted the percent Black variable with the number of private water wells in each town. These results are summarized in Table 12. I find that the coefficient on this interaction term is positive and statistically significant. Specifically, towns with a higher percent of Black residents and a higher number of private water wells are associated with a higher probability of banning fracking. After taking into account the increased vulnerability to risks to water faced by Black residents, the coefficient on the percent Black is now statistically insignificant. This result suggests that Black opposition to fracking activities may be related to their awareness of their communities' greater exposure to low-quality water.

Next, I present the results for the adoption of moratoria in Table 13. As before, towns in counties that use more water for livestock and towns in counties that have a higher recycling rate are associated with a statistically significant higher probability of adopting a moratorium, while towns with a greater history of drilling and towns with a higher percent of residents with only a high school degree are associated with a statistically significant lower probability of adopting a moratorium. Otherwise, the estimated coefficients for moratoria adoption are different from the coefficients for ban adoption in statistical significance, magnitude, and direction. In Appendix B, I explore the results for moratoria in more detail, differentiating the moratoria in various ways. Overall, I find that results for shorter moratoria are more similar to the results for bans because shorter moratoria are associated with subsequent ban adoption. Otherwise, the adoption of a moratorium continues to be inversely proportional to a town's vulnerability to water risks, confirming that an alternative theoretical framework—and not one based on resident analysis of benefits and costs—better explains moratoria adoption.

In terms of effect, a moratorium would only implicate the benefits and costs of shale development if the state were to lift its moratorium on shale development during the lifetime of the town moratorium. The probability of an effect is thus very small. This makes it less likely that these actions are adopted with the net costs of fracking activities in mind. It is more likely that the moratoria are symbolic gestures of support or opposition. If so, it is not surprising that some of the strongest predictors of moratoria adoption are the variables indicating previous drilling experience, which may proxy for industry influence, and the county recycling rate, which may proxy for environmental preferences.

Conclusion

Towns in New York and other states are deciding whether or not to allow fracking within their borders. In this chapter, I empirically investigate what predicts these local decisions. Overall, I find that vulnerability to risks to water plays a robust role in the decision to adopt a ban on fracking activities. Towns with more residents with greater reliance on private wells for drinking water or with greater reliance on healthy livestock are associated with a statistically significant higher probability of adopting a ban. In addition, industry presence and previous experience with drilling tend to decrease the probability that a town adopts a ban. Finally, environmental preferences, demographic characteristics, and organized political interests also predict whether a town will adopt a ban. In general, the results suggest that New Yorkers in towns where shale development is viable decide whether or not to adopt a ban on fracking based at least partially on perceived benefits and costs of shale development to their communities. In contrast, my results suggest that the adoption of a town moratorium, especially in light of the state's moratorium on fracking activities, may be mostly a symbolic gesture.

In Chapter I, I demonstrate that properties that rely on private water wells may face overall value losses due to nearby shale drilling when well violations are high. The preservation of property values has long been acknowledged as an important and acceptable reason for zoning classifications. It may be the case that New York residents oppose drilling and enact zoning regulation to preserve property-value losses from risk perceptions, too.

If bans are adopted to protect vulnerable water sources from actual or perceived water-contamination risks of drilling that may lead to property-value losses, then the IEA may be correct in thinking that more stringent regulations would decrease such bans. Without knowing the final form that the NYDEC regulations will take, towns in New York are banning fracking. The town actions suggest that residents are not convinced that the proposed NYDEC regulations protect their water sources sufficiently and, in the case of water contamination, provide adequate assurances of compensation and remediation.

In Chapter III, I discuss how state regulators could better manage the risks to water from fracking activities by strengthening regulatory safeguards, clarifying tort responsibility, and using insurance to ensure compensation and remediation. Such strategies would act to mitigate actual risks, alleviating some of the concerns of property-value losses. The availability of insurance to cover damages will further provide peace of mind to residents. Together, these strategies could make residents more tolerant of fracking activities in their areas and decrease the number of total bans on fracking activities.

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Tables

Table 7. Towns Adopting Bans or Moratoria in Counties on Shale Formations, 2010 to 2013.

Bans		Moratoria		
Andes	Milford	Alfred	Hopewell	Palatine
Augusta	Moravia	Andes	Huron	Paris
Bethel	New Hartford	Annsville	Italy	Penfield
Brighton	New Lisbon	Augusta	Jerusalem	Portage
Butternuts	New Paltz	Ava	Kirkland	Preble
Camillus	Niles	Avon	LaFayette	Remsen
Caroline	Olive	Barrington	Lansing	Rensselaerville
Cherry Valley	Onondaga	Benton	Ledyard	Richmond
Danby	Otisco	Berne	Lenox	Richmondville
DeWitt	Otsego	Blenheim	Lima	Rush
Dryden	Paris	Boonville	Lincoln	Sangerfield
Elbridge	Perinton	Brighton	Little Falls	Schoharie
Enfield	Plainfield	Bristol	Livonia	Scipio
Forestburgh	Pompey	Brookfield	Locke	Sennett
Fulton	Rochester	Burns	Manchester	Seward
Geneva	Roseboom	Butternuts	Manheim	Sidney
Guilderland	Rosendale	Caledonia	Marbletown	Skaneateles
Highland	Rush	Camden	Marcellus	South Bristol
Ithaca	Skaneateles	Canandaigua	Marshall	Spafford
Jerusalem	Spafford	Caroline	Mendon	Sparta
LaFayette	Springfield	Chester	Middleburgh	Springwater
Lumberland	Summerhill	Colden	Middlesex	St. Johnsville
Marbletown	Tusten	Conesus	Milo	Stafford
Marcellus	Ulysses	Cortlandville	Minden	Starkey
Marshall	Wales	Danube	Moravia	Torrey
Mendon	Warwick	DeWitt	Mount Morris	Trenton
Meredith	Wawarsing	Deerfield	Naples	Tully
Middlefield	Woodstock	Eaton	New Hartford	Vernon
		Elbridge	Newfield	Verona
		Enfield	Newport	Vienna
		Fabius	Niles	Wales
		Florence	Niskayuna	Waterloo
		Floyd	North Dansville	Wayne
		Forestport	Nunda	West Bloomfield
		Fulton	Olive	West Sparta
		Geneseo	Oneonta	Westerlo
		Genoa	Onondaga	Westmoreland
		Gorham	Otego	Whitestown
		Hartwick	Otisco	Yorkshire
		Highland	Owasco	

Notes. This list does not include towns in counties without known shale reserves.

Table 8. Sample Detail on Town Bans.

Town	Type	Prohibition
Camillus	Zoning	“The exploration of land for natural gas by horizontal drilling and hydraulic fracturing” is a prohibited use in all districts.
Cherry Valley	Zoning	“Heavy industry” is prohibited in all districts, and the definition of heavy industry includes “exploration for natural gas; extraction of natural gas; natural gas processing facilities.”
Danby	Zoning	Added a section on the “prohibition against the exploration for or extraction of natural gas and/or petroleum.”
Dryden	Zoning	Clarifying that oil and gas development activities, including fracking, were prohibited uses of land within the town.
Ithaca	Zoning	Clarifying that natural gas exploration, extraction, and related operations could not interpreted as allowable uses in the “light industrial zone.”
Lumberland	Zoning	Natural gas exploration, extraction, and related operations are listed as explicitly prohibited uses in all districts.
Middlefield	Zoning	Heavy industry and all oil, gas, or solution mining and drilling are prohibited uses in all districts.
New Lisbon	Zoning	Unlawful for any person to conduct “heavy industry” within the town, with the definition of heavy industry including exploration for natural gas; extraction of natural gas; natural gas processing facilities, among other things.
Plainfield	Zoning	“Heavy industry” is prohibited in all districts, with the definition of heavy industry including exploration for natural gas; extraction of natural gas; natural gas processing facilities, among other things.
Springfield	Zoning	Unlawful for any person to conduct “heavy industry” within the town, with the definition of heavy industry including exploration for natural gas; extraction of natural gas; natural gas processing facilities, among other things.
Tusten	Zoning	Activities expressly and explicitly prohibited in any zoning district include natural gas exploration, extraction, or production activities.
Ulysses	Zoning	Natural gas exploration, extraction, and support activities are not permitted in any zoning district.
Wales	Rights-Based Ban	“It shall be unlawful for any individual or corporation to engage in the extraction of natural gas or oil utilizing in whole or in part the process commonly known as and herein defined as hydraulic fracturing within the Town of Wales .”

Notes. The assorted bans detailed above were adopted in 2010 or 2011. Later bans tended to use similar language.

Table 9. Summary Statistics – New York Towns, in Counties on Shale Formations.

Variables	Obs.	Mean	Std. Dev.
Legislative Actions			
Adopted a ban on fracking activities, 2010-2013 (0/1)	688	0.081	0.274
Adopted a moratorium on fracking activities, 2010-2013 (0/1)	688	0.173	0.378
Adopted a ban or moratorium on hydraulic fracturing activities, 2010-2013 (0/1)	688	0.215	0.411
Adopted duration of moratoria, in months*	116	11.250	3.501
Water Variables			
Proportion Relying on Private Well Water, by county	688	0.326	0.183
Livestock Private Withdrawals, Million Gallons per Day, by county	688	0.672	0.398
Crop Irrigation Private Withdrawals, Million Gallons per Day, by county	688	0.323	0.376
Domestic Water Wells, by town (count)	688	65.201	71.944
Agriculture or Irrigation Wells, by town (count)	688	0.443	3.217
NYC, Syracuse, or Croton watershed area (0/1)	688	0.041	0.198
Intersects Any Aquifer (Principal, Primary, Sole-Source) (0/1)	688	0.257	0.437
Drilling Variables			
Vertical Well Development, before 2010 (count)	688	46.190	216.700
Horizontal Well Development, before 2010 (count)	688	0.544	2.880
Gas Well Development, before 2010 (count)	688	13.330	40.370
Oil Well Development, before 2010 (count)	688	16.010	139.800
Political Variables (county level)			
Proportion Active Democrats, Nov. 2008	688	0.243	0.093
Proportion Active Republicans, Nov. 2008	688	0.296	0.055
Proportion Active Independents, Nov. 2008	688	0.032	0.008
Proportion Active Green Party, 2008	688	0.002	0.001
Strong Democratic Party Affiliation, by county	688	0.124	0.086
Strong Republican Party Affiliation, by county	688	0.149	0.082
Recycling Variable (county level)			
Recycling Rate, by county	688	0.761	0.102
American Community Survey (5-year, 2006-2010)			
Median Household Income	688	52,028	11,517
Total Population Estimate	688	6,180	10,920
% Age 25+ w/ High School Degree	688	37.740	8.477
% Age 25+ w/ Bachelor's Degree	688	12.090	5.547
% Age 25 w/ More than a High School Degree	688	49.935	11.455
% Unemployed	688	6.903	3.028
% Black	688	2.360	4.114

Variables	Obs.	Mean	Std. Dev.
% Under 19 Years Old	688	25.740	4.861
% Owner-Occupied Housing	688	80.604	8.735

Notes. This list excludes towns in counties without known shale reserves. * Excludes moratoria that do not specify a duration. In regressions, these moratoria were coded as 36 months, which is the largest duration otherwise specified (for Niskayuna).

Table 10. Anti-Fracking Actions Adopted per Year.

	Bans	Moratoria
2010	2	8
2011	13	33
2012	21	75
2013	21	7
Total	57	123

Table 11. Main Results for Bans in New York Towns, Cross-Sectional Probit (reporting marginal effects).

Variables	(1)	(2)
Water Variables		
Proportion Relying on Private Well Water, by county	0.020***	0.014**
	(0.007)	(0.006)
Livestock Private Withdrawals, by county	0.008***	0.007***
	(0.002)	(0.002)
Crop Irrigation Private Withdrawals, by county	-0.002	-0.002
	(0.003)	(0.002)
Domestic Water Wells/1,000		0.014*
		(0.008)
Agriculture or Irrigation Wells/1,000		0.182**
		(0.080)
Drilling Variables		
Vertical Well Development/1,000	-0.074**	-0.064**
	(0.036)	(0.029)
Horizontal Well Development/1,000	-2.998***	-2.767***
	(0.942)	(0.940)
Political Variables		
Prop. Active Democrats, by county	0.042*	0.040**
	(0.026)	(0.019)
Prop. Active Republicans, by county	-0.170***	-0.125***
	(0.032)	(0.025)
Prop. Active Greens or Independents, by county	-0.581**	-0.471**
	(0.288)	(0.233)
Recycling Variable		
Recycling Rate, by county	0.044***	0.038***
	(0.015)	(0.012)
Demographic Variables		
Logarithm of Median Income	-0.010	-0.011**
	(0.006)	(0.005)
Logarithm of Town Population	-0.001	-0.001*
	(0.001)	(0.001)
% Age 25+ w/ High School Degree/1,000	-0.410*	-0.341*
	(0.218)	(0.178)
% Age 25 w/ More than a High School Degree/1,000	0.341**	0.300**
	(0.166)	(0.138)
% Unemployed/1,000	-0.024	-0.047
	(0.280)	(0.226)
% Under 19 Years Old/1,000	-0.471***	-0.392***
	(0.164)	(0.137)

Variables	(1)	(2)
% Black/1,000	0.312*	0.269*
	(0.185)	(0.150)
% Owner-Occupied Homes/1,000	0.235**	0.208***
	(0.096)	(0.080)
Observations	688	688

Notes. Robust standard errors in parentheses. Coefficients have been transformed to reflect the marginal effects on the probability of a ban. *** p<0.01, ** p<0.05, * p<0.1.

Table 12. Results for Bans with Race-Risk Interaction, Cross-Sectional Probit.

Variables	(1)
Water Variables	
Proportion Relying on Private Well Water, by county	0.014**
	(0.006)
Livestock Private Withdrawals, by county	0.008***
	(0.002)
Crop Irrigation Private Withdrawals, by county	-0.001
	(0.002)
Domestic Water Wells/1,000	0.010
	(0.009)
Agriculture or Irrigation Wells/1,000	0.213**
	(0.099)
Drilling Variables	
Vertical Well Development/1,000	-0.067**
	(0.031)
Horizontal Well Development/1,000	-2.955***
	(1.001)
Political Variables	
Prop. Active Democrats, by county	0.039*
	(0.021)
Prop. Active Republicans, by county	-0.134***
	(0.028)
Prop. Active Greens or Independents, by county	-0.520**
	(0.252)
Recycling Variable	
Recycling Rate, by county	0.042***
	(0.013)
Demographic Variables	
Logarithm of Median Income	-0.011**
	(0.005)
Logarithm of Town Population	-0.001
	(0.001)
% Age 25+ w/ High School Degree/1,000	-0.347*
	(0.202)
% Age 25+ w/ Bachelor's Degree/1,000	0.336**
	(0.156)
% Unemployed/1,000	-0.042
	(0.245)
% Under 19 Years Old/1,000	-0.426***
	(0.152)

Variables	(1)
% Black/1,000	0.008
	(0.225)
% Owner-Occupied Homes/1,000	0.205**
	(0.087)
Interaction Domestic Water Wells x % Black	0.014**
	(0.007)
Observations	688

Notes. Robust standard errors in parentheses. Coefficients have been transformed to reflect the marginal effects on the probability of a ban. *** p<0.01, ** p<0.05, * p<0.1.

Table 13. Main Results for Moratoria in New York Towns, Cross-Sectional Probit.

Variables	(1)	(2)
Water Variables		
Proportion Relying on Private Well Water, by county	-0.290***	-0.257***
	(0.097)	(0.094)
Livestock Private Withdrawals, by county	0.099***	0.091***
	(0.028)	(0.027)
Crop Irrigation Private Withdrawals, by county	-0.035	-0.027
	(0.043)	(0.042)
Domestic Water Wells/1,000		-0.053
		(0.169)
Agriculture or Irrigation Wells/1,000		-40.218*
		(20.980)
Drilling Variables		
Vertical Well Development/1,000	-0.761***	-0.722***
	(0.282)	(0.270)
Horizontal Well Development/1,000	-7.643*	-7.040
	(4.595)	(4.365)
Political Variables		
Prop. Active Democrats, by county	-0.503	-0.459
	(0.417)	(0.411)
Prop. Active Republicans, by county	-0.644	-0.687*
	(0.397)	(0.393)
Prop. Active Greens or Independents, by county	-1.922	-2.200
	(3.998)	(3.847)
Recycling Variable		
Recycling Rate, by county	0.644***	0.615***
	(0.169)	(0.161)
Demographic Variables		
Logarithm of Median Income	-0.081	-0.049
	(0.094)	(0.091)
Logarithm of Town Population	-0.011	-0.006
	(0.015)	(0.015)
% Age 25+ w/ High School Degree/1,000	-11.773***	-11.527***
	(3.793)	(3.642)
% Age 25 w/ More than a High School Degree/1,000	-3.379	-3.601
	(3.056)	(2.906)
% Unemployed/1,000	-3.727	-3.326
	(4.272)	(4.086)
% Under 19 Years Old/1,000	-4.510	-4.247
	(2.869)	(2.719)

Variables	(1)	(2)
% Black/1,000	-7.226*	-6.946*
	(4.338)	(4.082)
% Owner-Occupied Homes/1,000	1.348	1.143
	(1.711)	(1.622)
Observations	688	688

Notes. Robust standard errors in parentheses. Coefficients have been transformed to reflect the marginal effects on the probability of a moratorium. *** p<0.01, ** p<0.05, * p<0.1.

CHAPTER III

FRACTURED SYSTEMS: HOW TO MANAGE RISKS TO WATER FROM SHALE DEVELOPMENT

Introduction

Advances in drilling techniques, namely horizontal drilling and high-volume hydraulic fracturing (fracking), have allowed operators to profit from oil and gas extracted from the extensive shale (unconventional) formations found in the United States. These technological advances combined with the high price of natural gas in the mid-2000s have resulted in a drilling boom that exposes more areas, including heavily populated and environmentally sensitive areas, to the ordinary as well as the extraordinary perils associated with drilling activities. In Chapters I and II, I empirically examined how perceived or actual risks of shale development affect property sales in a Pennsylvania county and legislative decisions by New York towns. In general, I find that risks to water feature prominently in both contexts—that is, these risks are particularly salient for individuals deciding whether to live near shale development or whether to allow it in their communities at all.

Specifically, in Chapter I, I find that properties that rely on private water wells in Washington County, Pennsylvania may face property-value losses due to actual or perceived risks of nearby shale development, especially when the properties do not receive offsetting royalty payments from nearby operators. In addition, the values of all properties with a nearby horizontal well decrease when state regulators find and reveal high numbers of environmental, health, and safety violations at shale wells. Overall, my results show that the average losses due to risk perceptions are not large. My findings also suggest that shale development could pass a local benefit-cost test—wherein winners could more than compensate losers[60]—if drilling risks are well managed. Property-value losses may even be prevented completely if vulnerable properties are appropriately protected from risks and if compensation for damages is readily available.

Despite the possibility of local net benefits on average, concerns about significant drilling externalities and resulting losses to some property values may lead communities across the United States to prohibit shale development outright. In Chapter II, I find that shale-rich New York towns with a higher proportion of residents who rely on private water wells are more likely to prohibit shale development in their jurisdictions. This finding is robust to different definitions of reliance on private water wells, and the effects are distinct from other relevant determinants of banning behavior, such as environmental preferences, political affiliations, and demographic characteristics.

States have primary authority to regulate most externalities associated with shale development and onshore drilling in general (Richardson et al. 2013). Typically, when a socially beneficial activity generates externalities, governments can engage three tools to manage these externalities: regulations, tort liability, and liability insurance mandates. Governments can promulgate all kinds of regulations, but under an economic framework, regulations are only justified if they generate net benefits to society. Tort litigation, on the other hand, is initiated by private parties seeking compensation for harms allegedly caused by other parties. But, governments can decide how broadly to define tort liability,

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[60] This is a condition of Kaldor-Hicks efficiency, which underlies benefit-cost analysis (Adler and Posner 2006). A full benefit-cost analysis is outside the scope of this study. Other studies suggest that shale development provides benefits that are likely to exceed costs (Considine, Watson, and Considine 2011).

and the extent of tort liability can regulate private behaviors. Finally, liability insurance is a market tool available to companies to manage risks from their activities. Governments can mandate liability insurance coverage, ensuring that only companies that are able to pay for expected damages engage in an activity. When deployed effectively, these three tools—regulation, tort, and insurance—make up a risk-management system that creates incentives for optimal activity levels, acceptable risk-taking, and adequate environmental protection.

In this chapter, I examine some of the features of such a system. First, I discuss the risks to water from shale development, dividing resulting harms up into four categories broadly based on the timing of pollution discharges and the manifestation of harms. Next, I discuss how regulations can help incentivize appropriate risk-taking by operators. Essentially, regulators should require risk-mitigation expenditures that pass a benefit-cost test, taking into account all immediate environmental and other costs of adverse well events. Regulators should use alternative regulatory interventions, however, to manage uncertain risks. I then discuss how tort incentives would ensure that operators comply with these regulations while providing compensation to victims for immediate harms notwithstanding regulatory compliance. Finally, I discuss how and when insurance mandates could work with comprehensive regulatory and tort regimes to ensure that a pool of money is available to compensate victims and remediate the environment. Overall, governments could use these tools to provide responsible protection against all categories of harms to water from shale development.

Risk Categories

Ordinary risks of drilling include risks of contamination from blowouts, improper waste disposal, and inadequately sealed abandoned wells, the cumulative environmental effects of which could be significant. Shale drilling techniques also come with uncertain risks of groundwater and surface water contamination from fracking fluid, fracking wastewater, or methane gas that could pass through underground fracture pathways into drinking-water aquifers or that could get spilled on the surface and seep into the water supply.[61] In Table 14, I divide the risks to water from extensive onshore drilling into categories based on whether harms are caused by sudden releases versus gradual releases and on whether the adverse effects on health, property, or the environment are immediately manifested versus manifested long after the initial release of contamination.[62] Although it is useful to consider the risks that arise from different contaminants or during different stages of the drilling process when devising regulations, it is often the timing of harms that is relevant for implementing ideal combinations of regulatory, liability, and insurance tools. I refer to these categories in my discussions.

The examples of risk pathways and harms that fall into each category in Table 14 are meant to be illustrative, not comprehensive. Category I and II risks to water are characterized by immediate detection of harms. These pollution releases can be contained quickly, and the damage will often involve property and environmental damage, with few adverse health effects. Although the extent of immediate damages can be high, the

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[61] Appendix C provides a detailed overview of contaminants and contamination pathways.

[62] Dana and Wiseman (2014) present a different categorization of risks by activity and the nature of risk.

probability that these damages would reach catastrophic scales is small.[63] Category I risks stem from sudden releases, such as accidental spills, discharges, or blowouts that can contaminate nearby soil or water. Category II risks stem from gradual releases, such as slowly leaking on-site wastewater storage pits that can contaminate nearby soil or water. It might be more difficult to quickly detect a gradual release and link it to immediate harms, but incentives should be in place for operators to do so.

Category III and IV risks are characterized by latent manifestation—and therefore delayed detection—of harms. A large proportion of these risks include the uncertain risks of shale development, such as the risk of pollutants moving through fracture systems over the course of years to enter a water source (Category III) or the risk that individuals may develop cancers as a result of previous exposures to pollution (Category III or IV). Some future harms relate to well completion and abandonment procedures or to wastewater disposal. If adequate procedures are not in place to seal wells, then these wells may develop leaks and gradually discharge pollution over time into the surrounding soil or water (Category IV). Resulting harms are likely to involve property and environmental damage but may also include allegations of adverse health effects, such as cancers caused by long-ago contamination events.

Regulation's Role

Economists, and most people, would agree that government regulation should produce more benefits than no regulation at all—that is, the social benefits of the regulation should be higher than the social costs of implementing and complying with the

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[63] Later, I discuss strategies for dealing with low-probability catastrophic damages.

regulation. This concept is often easier for people to support in the abstract than in particular circumstances, especially when it comes to protecting people from environmental risks; valuations of nonmarket entities may vary widely across people, and people often distrust the ability of the government to acknowledge all the benefits of regulation. Hence, when it comes to environmental protection, some call for maximum risk reduction. In reality, however, it is neither possible nor desirable to eliminate all risks from an activity. The time and money invested into reducing small risks may be time and money that could have been spent more efficiently in other contexts. Governments must be able to prioritize risks and do more good than harm with their policy interventions. Such a goal would be accomplished when governments require only those drilling risk-mitigation expenditures that pass a benefit-cost test or, in other words, generate net benefits to society.[64]

Roughly speaking, benefit-cost analysis forces regulators to explicitly list, quantify, and when possible, monetize the expected benefits and costs of a proposed regulation, taking into account alternatives that might achieve similar goals at lower cost (U.S. Office of Management and Budget 2011). Regulators then pick the regulatory alternative that maximizes net benefits, subject to statutory constraints. Benefit-cost analysis is already a feature of most major federal rulemaking. Executive Order No. 12,866 requires federal agencies to engage in benefit-cost analysis (referred to as regulatory impact analysis) before promulgating major regulations (Clinton 1993). Studies suggest that regulatory impact analysis has improved the quality of many federal

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[64] Preferably, among net beneficial regulations, regulators would also choose the risk-control option that maximizes net benefits or, in other words, minimizes the sum of the costs of losses and the costs of avoiding losses.

regulations (*e.g.*, Morgenstern 1997), and the procedure, though still controversial, forms the foundation of federal regulatory policy (Sunstein 2002).

Currently, shale development is regulated by states, and state regulation is not explicitly constrained in any way. Some scholars and commentators are calling for states to implement shale regulations based on "best practices."[65] Already, the American Petroleum Institute has developed a set of industry "best practices,"[66] and one organization offers certification to Appalachian Basin operators for compliance with a set of water and air performance standards based on "leading industry practices."[67] But, the definition of "best practices" is rarely provided.

One exception is Merrill and Schizer (2013) who roughly define best-practice regulations as rules based on best-available technologies. Specifically, the authors state that these practices "reflect the 'state of the art,' meaning something more stringent than common practice that is still technologically and economically feasible," and that the resulting regulations "are usually defined by the state of existing technology instead of a rigorous assessment of costs and benefits" (Merrill and Schizer 2013).

In this chapter, I urge regulators to engage in a rigorous assessment of costs and benefits and adopt only those best-practices regulations that generate net benefits to society. Qualifying regulations can take many forms—such as command-and-control rules that specify operating practices or flexible performance standards that require a level of environmental protection—as long as the likely benefits are shown to outweigh

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[65] For example, Peter Behr. 2013. "Insurance Issues Loom Over Shale Gas Development." *E&E EnergyWire*, August 1.

[66] American Petroleum Institute. 2012. "Overview of Industry Guidance/Best Practices on Hydraulic Fracturing (HF)." http://www.api.org/~/media/files/policy/exploration/hydraulic_fracturing_infosheet.ashx.

[67] Center for Sustainable Shale Development. 2014. "Certification." https://www.sustainableshale.org/certification/.

the costs. An example of this type of constraint on regulation can be found in the current federal regulations in place for oil-and-gas operations conducted on the Outer Continental Shelf, which call for "the use of the best available and safest technologies . . . except where the Secretary determines that the incremental benefits are clearly insufficient to justify the incremental costs of utilizing such technologies."[68] In many cases, benefit-cost analysis will point toward rules or incentives that are based on best-available technologies, but the analysis will generate transparency and will help shed light on uncertainties that require further research.

In practice, the analyses should account for all the costs and benefits of shale development in an area, including national, state, and local impacts. Under the "matching principle" wherein the lowest level of government that geographically encompasses the costs and benefits of an activity is made responsible for regulating the activity (Buchanan and Tullock 1962), then, the federal government would regulate shale development and condition site-specific permits on compliance with cost-effective regulations perhaps tailored to local conditions. A national shale development regulatory scheme would also allow the government to take advantage of greater resources and potential benefits overlap when generating site-specific benefit-cost analyses. The current political atmosphere, however, suggests that transferring authority over regulation and permitting of drilling on nonfederal lands from states to the federal government is unlikely.[69] That

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[68] 43 U.S.C. § 1347 (2014). One of the motivating principles behind the requirement of "best available and safest technologies" was ensuring that operators use "technologies that allow for the safest and most reliable operations, which are cost-effective" (Khorsandi 2011).

[69] It may be more likely that the federal government could gain control of particular aspects of shale-development regulation in which the benefits of uniformity and concentrated expertise outweigh the benefits of tailoring. One such area may be the disclosure of fracking chemicals. Fourteen states require disclosure (Richardson et al. 2013), but most states have exemptions that provide for varying levels of trade secret protection. But, drilling companies often operate in multiple states. If the companies use similar chemicals in their fracking fluid across different states, then their secrets are only protected as far as in the

said, Spence (2013) argues that most impacts are subsumed within state boundaries, suggesting that state regulation may be sufficient.[70] In addition, state-specific analyses would allow for baseline risk-mitigation requirements that are tailored to state-specific conditions. For example, the potential benefits of risk mitigation will be higher in states with more people who rely on private water wells for drinking water, which would tend to justify greater expenditure on risk mitigation in those states.[71]

The question then arises whether local governments should be more involved in regulating shale development within their jurisdictions. Spence (2014) argues that, because the majority of impacts are local and because locals are likely to have the most intense preferences, local decisionmaking can in some circumstances better maximize welfare. But, as he acknowledges, local regulation is only likely to consider local benefits and costs, and local benefits and costs do not reflect full benefits and costs that occur on a state, regional, and sometimes national level. Because my proposal relies on an analysis of all benefits and costs, local regulation alone would not suffice. In practice, it would also be difficult if not impossible for local governments to satisfy a requirement of engaging in comprehensive benefit-cost analysis before requiring risk-mitigation practices or banning shale development outright. Meanwhile, a state that employs benefit-cost analysis would take into account local impacts when choosing appropriate

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state requiring the most disclosure. If so, then a federal disclosure standard that weighs the costs of revealing trade secrets against the benefits of quickly identifying potential environmental hazards in the event of accidental pollution releases would be an improvement.

[70] In a response to Spence (2013), Burger (2013) argues that state regulation is unlikely to take into account some interstate and national impacts of shale development. Other scholars have also weighed in on the question of whether federal, state, or local regulation is best (*e.g.*, Nolon and Polidoro 2012; B. Warner and Shapiro 2013; Craig 2013; Burleson 2013).

[71] So far, however, researchers have not found many statistically significant associations between observed regulatory heterogeneity and environmental and demographic variables (Richardson et al. 2013), suggesting room for improvement.

regulation and could incorporate consideration of the intensity of relevant preferences into its analysis.[72]

What may be more effective, then, is a state regulatory scheme with baseline cost-effective regulations that then conditions site-specific permits on additional risk-mitigation practices tailored to local conditions. Such a strategy would require significant input from local governments. It is possible that New York's Supplemental Generic Environmental Impact Statement (SGEIS) regulations, when finalized, will reflect such a system. The current revised draft SGEIS would preempt local government regulation of oil-and-gas development[73] but would require site-specific environmental review, would notify relevant local governments before approving any shale development permits in their jurisdiction, and would ensure consultation with local governments if a proposed permit application would be inconsistent with local laws, regulations, or policies.[74] In this way, the state would consider all possible costs of shale development as local governments would have a systematic way to inform the state of any significant adverse environmental impacts that might not have been addressed in the state review.[75]

Besides ensuring that shale regulations are net beneficial, a benefit-cost requirement would increase the transparency of risks, promote public understanding of risks, and help identify cost-effective alternatives in some contexts. In Chapter I, I find evidence that individuals look to information on environmental, health, and safety

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[72] For example, analysts might consider certain resources to be more valuable, justifying greater protection measures.

[73] The question of what New York local governments could do notwithstanding state regulation is currently being litigated. In August 2013, New York's highest court, the Court of Appeals, agreed to hear two cases challenging town bans, and its decision is pending. Chapter II provides details on these cases.

[74] 2011. "Revised Draft SGEIS on the Oil, Gas and Solution Mining Regulatory Program." http://www.dec.ny.gov/energy/75370.html.

[75] Local governments might still wish to mitigate some of the truly local impacts of shale development using tools at their disposal to the extent allowable by law (Nolon and Polidoro 2012).

violations to update their beliefs about the riskiness of nearby shale wells. Violations, however, do not provide clear risk information. Gayer, Hamilton, and Viscusi (2000) previously found that the U.S. Environmental Protection Agency's release of risk information about nearby Superfund sites[76] generally lowered individuals' perceptions of site risks, a result that suggests that the initial reactions to site risks were too high. Similarly, accurate risk information contained in benefit-cost analyses may reduce public concern by potentially demonstrating that many risks to water are small, eliminating the violations-related property-value effects.

In addition, in Chapter I, I find that properties that rely on private well water are most vulnerable to value losses from nearby shale development, and in Chapter II, I find that concern for such properties may also drive banning behavior. It is possible that extending public water to properties that now rely on private well water may be found to be a cost-effective solution to some of the ordinary risks of shale development that otherwise fall on these properties. Or, states may find it worthwhile to provide support to private water well owners for water-quality testing and maintenance. A careful accounting of benefits and costs could reveal such alternative risk-mitigation strategies.

To keep the calculations tractable, the benefits of regulation should focus on avoiding immediate environmental harms—in other words, those caused by Category I and II risks to water. These risks are known and quantifiable to a large extent based on data from the last decade or so of shale development, as well as decades of conventional onshore oil-and-gas drilling. In addition, there are resources available to states to help

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[76] Superfund sites are sites contaminated with hazardous substances that are managed under the Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S.C. § 9607 (2014).

ensure that their regulations cover most sources of immediate risks.[77] State regulators could also solicit information from industry experts to help calculate costs.[78] Finally, state regulators could further decrease administrative costs by relying more on flexible performance standards to achieve regulatory goals, though the regulators would still have to justify the regulatory goals from a benefit-cost perspective.

Some Category IV risks are also amenable to cost-effective regulation. Specifically, for Category IV risks such as future leaks in disposal wells or improperly plugged abandoned wells,[79] regulators should require companies to post assurance bonds at well completion (Dana and Wiseman 2014). Once the operator proves that it has implemented cost-effective features to ensure that the wells are unlikely to leak, the operator may retrieve the bond that it posted. The bond would thus counteract the incentive for companies to simply abandon or improperly seal wells once drilling or disposal is complete.

But, generally speaking, it would be difficult for regulators to assess the benefits and costs of risk-mitigation strategies to manage Category III risks and some Category IV risks, specifically those that manifest in the future through highly uncertain pathways. Because harms are yet to manifest (if they manifest at all), the calculation of benefits of specialized risk-mitigation strategies would be a speculative venture. Command-and-

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[77] The State Review of Oil and Natural Gas Environmental Regulations, Inc. (STRONGER), a nonprofit, multi-stakeholder organization with expertise in oil-and-gas regulations, offers a voluntary review of state oil-and-gas laws and regulations, including fracking-specific regulations, but so far, only six states have availed themselves of the fracking-specific regulatory review. STRONGER, Past Reviews, http://www.strongerinc.org/past-reviews.

[78] Concern about regulatory capture that might lead to less-stringent regulations would be mitigated if regulation is supplemented with tort liability that would hold operators responsible for all damages from drilling activities. As I discuss in the next section, comprehensive tort liability will provide incentives that push regulators to adapt cost-effective operating practices.

[79] These harms do not manifest later, but rather they may actually occur later if proper precautions are not taken in advance.

control regulations, the most common form of state regulations,[80] are particularly unlikely to provide the flexibility necessary for regulators to adapt to new information on these risks and the magnitude of harms. In this context, information-generating regulations about risks or pathways may be most valuable. The government could incentivize research (or conduct research itself) to obtain more information about the risks and respond appropriately as soon as information is available. These tasks would be most efficiently accomplished at the federal level to avoid repetition and to take advantage of considerable resources, but if an enhanced federal role is unlikely at this time, then states could take up this research role.

As the government awaits the results of long-term studies, regulators generally have two options: err on the side of caution and prohibit or significantly reduce the extent of shale development with stringent regulation or regulate lightly now and learn about these risks as development unfolds. The first option is embodied in the precautionary principle, which states that those wanting to take an action bear the burden of proving that the action does not create a risk of harm to the public or the environment. This principle is often thought to be too strong, prohibiting many net beneficial actions. There are circumstances, however, where caution is ideal. For example, Arrow and Fisher (1974) find that it might be optimal to err of the side of underdevelopment of a resource if development of the resource would cause irreversible environmental harm or if preservation of the resource is likely to have a high value in the future. In the case of contamination risks to water from shale development, current evidence does not suggest

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[80] Currently, more than eighty percent of state regulations are command-and-control regulations and about one percent are flexible performance standards (Richardson et al. 2013). The rest rely on case-by-case permitting and other methods.

that contamination would be irreversible, though it may be costly to clean up contaminated water sources.[81] If so, the second option may be preferable.

The second option is only reasonable, however, if researchers actively investigate the uncertain Category III and IV risks to water. Unfortunately, operators might not have adequate incentives to investigate the nature of uncertain pathways and latent harms. By definition, any harms manifest later, so operators would have to anticipate future tort liability to invest in this research now.[82] Tort litigation could help though—as cases enter the system, large judgments against operators may mobilize research (Hersch 2002). In the short term, however, the government would have to either incentivize research or conduct its own research into latent harms and uncertain pathways. For example, the government could require operators to invest a certain amount into research conducted by neutral scientific or research bodies. The government could also use taxes on the oil-and-gas industry to pay for the costs of conducting this research itself. Research could range from passive health monitoring of specific populations exposed to a major pollution event to active testing of uncertain risk pathways. For example, the U.S. Department of Energy injected fracking fluid with tracer chemicals into a drilling site in order to monitor the process of the fluid over several years.[83] Similar projects could occur at different shale formations and provide useful information to regulators, the public, and courts. When given the appropriate weight, the information could help set future regulatory standards and verify causation in tort.

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[81] I note, however, that there may be other risks of shale development that are irreversible and require a cautionary regulatory approach.

[82] Some tort plaintiffs alleging immediate harms from adverse well events are also calling for medical monitoring costs and may later hold operators responsible for latent health harms. For example, see Strudley v. Antero Res. Corp., 2013 WL 3427901 (Colo. App. July 3, 2013).

[83] Kevin Begos. 2013. "DOE Study: Fracking Chemicals Didn't Taint Water." *USA Today*, July 19.

Tightening Tort

Government regulation, even net beneficial regulation, may not sufficiently deter undesirable behaviors if the probability of detection and the resulting fines are low.[84] But compliance with net beneficial operating practices can be achieved through other mechanisms that force operators to pay for the externalities that they generate. For example, tort law, the body of law that deals with harms that occur outside of contractual relationships, can supplement the deterrence objectives of regulatory schemes by deciding when injurers are liable for their externalities and must thus compensate their victims. In this way, the tort system ensures that potential defendants only take those actions in which the benefits exceed the costs, exactly the incentives imposed by a rational regulatory system.

As of now, there is opportunity for states to increase the effectiveness of the tort system to manage the risks of shale development because key cases have yet to be decided in many states new to drilling. For example, states could expand the definition of liability, inform the selection of a liability standard for drilling-related harms, and decrease some of the difficulties plaintiffs face in establishing causation.

In order to establish a defendant's liability, the tort plaintiff must present prima facie evidence showing, at the minimum, that (1) the plaintiff suffered harm and (2) the defendant's activity caused the harm. Courts typically apply one of two liability standards: negligence (the default in many contexts) or strict liability. Under a negligence

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[84] Earthworks, for example, has argued that many states do not have the enforcement capacity to keep up with rapid shale development (*e.g.*, Earthworks 2012). Fines do not seem high enough to make up for the low probability of detection.

rule, the plaintiff would additionally need to show that the defendant owed and violated a duty to the plaintiff to take reasonable care when engaging in the activity in order for courts to impose liability on the defendant. Increasingly, however, defendants that engage in dangerous activities are held to a strict liability standard, which imposes liability on defendants for all the harms their actions cause regardless of whether the defendants are negligent. Theoretically, either form of liability can result in defendants taking the socially optimal level of care, defined as the level of care that minimizes total social costs after taking into account the costs of exercising care and the reduction in accident risks (Shavell 2004). But, under a negligence rule, courts would have to determine the defendant's level of care and calculate the socially optimal level of care.

Just as tort litigation can support the objectives of a net beneficial regulatory regime, such a regulatory regime can increase the efficiency of tort litigation. If courts apply a negligence rule to drilling operators, a set of net beneficial regulations would ease the court's decisionmaking task; the court would only need to determine whether the defendant violated relevant regulations to determine whether the defendant's actions fell below the standard of care. In fact, Merrill and Schizer (2013) propose such a regulation-and-tort integrated system for managing the risks of shale development, except that they urge regulations to adopt best practices based on best-available technologies. In their scheme, compliance with best-practices regulations would create a presumption that the defendant exercised reasonable care, subject to rebuttal by the plaintiff. If the best-practices regulations are not those that maximize net benefits, however, then the standard of care may not coincide with the socially optimal standard of care. For example, if the best-practices regulations minimize expected accident losses without considering costs, then they would in effect require the highest level of care and not the socially optimal level of care. Under an economic framework, the regulations would balance the costs and benefits of risk-mitigation strategies (as discussed in the previous section) and would not necessarily be based on best-available technologies, thereby keeping the resulting level of care at the socially optimal level of care.

Alternatively, courts can hold the operator strictly liable for resulting harms. Strict liability would also ease the court's decisionmaking task by removing the comparison of the defendant's level of care to the socially optimal level of care. It may also make sense to hold operators strictly liable for harms as operators may have easier access to insurance to pay for environmental harms that occur even when operators take reasonable care. Homeowner policies tend not to cover contamination risks of nearby shale development, but insurers can purchase specialized coverage to cover third-party harms, as discussed in the next section. Finally, strict liability has the added benefit of discouraging excessive activity levels (Shavell 2004). Because operators do not pay for resulting harms when they take due care under a negligence rule, they increase their activity levels so long as the benefits of additional activity outweigh their costs of taking due care. Under a strict liability rule, however, operators choose an activity level where their net utility (benefits minus costs of care) is higher than total expected harms, which is the socially optimal level of activity. If a state applies strict liability to operators, compliance with net beneficial regulatory standards should prevent the assessment of punitive damages against the operator even if compliance does not absolve the operator from liability for harms.

Beyond setting a liability standard, legislatures could create a liability regime for contamination by onshore drilling operators. This could be similar to what the federal government currently does for sites contaminated with hazardous substances (referred to as Superfund sites) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Specifically, CERCLA imposes strict liability for contamination by hazardous substances not only on current operators or owners of sites, but also on past operators or owners, transporters of hazardous substances, and disposal arrangers. In fact, some fracking-related spills may already trigger CERCLA liability. Fracking fluid contains about a half to two percent of chemical additives, some of which could be considered hazardous substances (U.S. House of Representatives 2011). And, if so, a sizeable spill of the fluid on the surface might trigger emergency response action under CERCLA, even though the purposeful injection of fracking fluids for well stimulation is not federally regulated.[85] To the extent not preempted by CERCLA, states could create similar liability systems for shale operators, where any spill of fracking fluid or wastewater could trigger cleanup responsibility.[86] In addition, the expansion of cleanup liability for such spills to parties besides operators may produce incentives for other involved parties to monitor the activities of those with whom they choose to work.

Although the tort system has the potential to efficiently regulate shale development, it has certain disadvantages, some of which can be mitigated with additional regulation. First, there is the problem of judgment-proof injurers (Shavell

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[85] In the 2005 Energy Policy Act, Congress amended the definition of "underground injection" under the Safe Drinking Water Act to exclude the injection of fracking fluid in the fracking operation itself, unless the fracking fluid contains diesel. 42 U.S.C. § 300h.

[86] Notably, however, CERCLA exempts oil and natural gas from the definition of a hazardous substance, meaning that spills of oil and gas do not trigger these reporting and liability requirements. 42 U.S.C. § 9601(14). In the case of shale development, it does not seem reasonable to require cleanup of natural gas, however, because the gas may be naturally present. In the case of alleged contamination by methane migration, then, it might be better for states to directly address causation hurdles, as I discuss next.

2004). These injurers face diminished incentives to mitigate risks because, even if disaster ensues, they will not be able to pay for damages. Victims can sue these injurers in tort, but there will be no funds available to compensate the victims and remediate harms. Regulatory interventions, however, could prohibit judgment-proof drilling operators. Specifically, regulators could require operators to purchase liability insurance that would cover expected immediate harms, as discussed in the next section.

Second, tort litigation is characterized by high transaction costs. Using insurer data, Hersch and Viscusi (2007) find that on average the total transaction costs for each dollar received by claimants are $0.75 for all claims and $0.83 for litigated claims. In addition, Hersch and Viscusi find that the main factors that influence litigation and defense costs for insurers were the scale and the complexity of the case—and environmental litigation, especially with causation often disputed, likely falls into the category of high complexity. It is possible that states could reduce transaction costs by clarifying liability standards to promote settlement of claims.

Finally, it is difficult for plaintiffs to prove causation and assign guilt in tort for water contamination from drilling activities (Jordan 2011; Hall 2013). A plaintiff must establish that the defendant's actions caused the harm in order to prevail in a tort claim. Sudden or gradual pollution spills at drilling sites, for example, can cause contamination of nearby water sources, but contamination can also be naturally present or be due to other human activities, such as the use of pesticides in agriculture. Even if drilling activities cause contamination, multiple operators can contribute to the contamination, making it difficult to hold any one company at fault.

Clear rules may provide some relief by creating default liability under certain conditions. For example, states could require operators to provide baseline test results if they want to allege that contamination in a water source was preexisting. This is essentially the liability rule in Pennsylvania, promoting baseline testing of nearby water wells without explicitly requiring baseline testing. As of now, only eight states require operators to test nearby water wells prior to drilling (Richardson et al. 2013). Texas and Oklahoma, states with significant shale development, have no such requirements. Noncompliance with testing requirements could factor into tort liability as it does in Pennsylvania—that is, operators that fail to test wells prior to drilling could be presumptively liable for any contamination—thereby decreasing some of the difficulties plaintiffs have in proving causation.

Although such strategies may reduce some causation burdens, they are unlikely to help plaintiffs that seek to establish causation between latent harms and shale development (Category III and IV risks). Courts may be hesitant to hold operators responsible for contamination or contamination-related harms that arise long after drilling has ceased. The amount of time that has elapsed also increases the likelihood that other factors contributed to the harm. Proactive research into these risk pathways would also work to support causation for true latent harms that might feature in future tort litigation.

And, if states fail to support such research, tort litigation could still play a useful, albeit costly, role in mobilizing research into latent harms. This could arise if future juries award large damages to plaintiffs regardless of whether the plaintiffs prove causation when there is little scientific evidence to dispute causation.[87] Hersch (2002) found that

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[87] Such occurrences have been documented in previous tort litigation. For example, after a prominent tort case in which the plaintiff alleged latent harms from her silicone breast implants, two jurors indicated after

litigation on breast-implant safety prodded the U.S. Food and Drug Administration (FDA) into action. When breast implants first became available on the market, the FDA had not required implant manufacturers to provide any information on the long-term safety of implants and did not initiate any such studies until after numerous plaintiffs had won multimillion dollar awards through tort litigation. Of course, it is preferable for regulators to require safety information or invest in research before large-scale tort litigation as potential plaintiffs will not have the necessary resources to support scientific research, and judges and juries will not have the expertise to evaluate the research. But, litigation could still act as an important backstop, ensuring that regulators do not ignore the difficult-to-understand latent harms from shale development.

Insurance Mandates

Finally, insurance mandates should play a role in comprehensive management of risks to water from shale development (Dana and Wiseman 2014). Insurance requires companies to pay premiums before any harms occur, thus forcing companies to "save" money in advance to pay for future harms. When clear regulatory standards are in place and when tort liability is well defined, a liability insurance regime can successfully mitigate environmental risk and ensure that funds are available to compensate victims and remediate the environment.

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the decision that while they did not think that silicone caused the plaintiff's disease, they awarded her $5.2 million in compensation because she was sick and needed the money and because there was no evidence that silicone was safe (Hersch 2002).

Benefits of Insurance

At first glance, the risk-mitigation benefits of insurance are counterintuitive. Liability insurance is actually a solution to the problem of risk-averse potential injurers either exercising too much care to avoid liability or avoiding the activity altogether when they face strict liability for harms. Both excessive care and suboptimal activity levels reduce social welfare. Therefore, the usual benefit of liability insurance is that injurers could be risk neutral instead of risk averse and generate an optimal (*i.e.*, higher) level of risk. In addition, the purchase of insurance itself could diminish the insured's incentives for risk reduction, a phenomenon referred to as moral hazard. Essentially, a party (the insured) may take on more risks when another party (the insurer) becomes the one responsible for paying for the consequences of the risks.

Hence, the role of insurance in risk mitigation is not a foregone conclusion. The key conditions for insurers to function as pseudo risk regulators is their ability to condition favorable premiums on the use of sound operating practices and to monitor policyholders to ensure compliance. Scholars disagree about whether insurers monitor,[88] but arguably, if claim payment is conditional on complying with the premium conditions and if tort litigation generally reveals the actions taken by the operator prior to an accidental release of pollution, then policyholders would have incentives to adhere to insurance conditions. But, even then, the insurer must condition premiums on compliance with some set of operating practices.

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[88] Some scholars point to examples where such monitoring occurs and improves outcomes (Ben-Shahar and Logue 2012), while others argue that insurers' monitoring capacity and history have been overstated (Abraham 2011). At least one energy insurance provider, Energi, Inc., has revealed to media that its underwriting process does include a compliance audit of a client's operations to ensure that safety and loss-prevention standards are followed. Peter Behr. 2013. "Insurance Issues Loom Over Shale Gas Development." *E&E EnergyWire*, August 1.

Once again, a rational regulatory system could enhance the beneficial properties of insurance. Specifically, premiums could be conditioned on the net-beneficial regulations discussed previously.[89] This would ensure that the resulting standard of care would continue to be the socially optimal standard of care. This system, however, would generally not work well for Category III and IV risks to water because state regulations would not specifically cover those risks. But, as I discuss later in this section, this gap is not relevant in this context as insurance should not be required to cover latent harms.

Finally, an insurance mandate can improve compensation outcomes by barring judgment-proof operators from engaging in drilling.[90] The insurance requirement would need to be set at an optimal coverage amount equal to the expected value of tort harms; otherwise, it might deter too many firms from entering the market.

Availability of Insurance

There are several types of insurance plans available today that can be used to control some of the water-contamination risks of fracking and drilling in general. First, there are traditional commercial general liability (CGL) policies. These policies were first offered in 1940 and provided protection for liability for damages from accidental events (including pollution discharges) that occurred during the policy period ("occurrence-based" coverage).[91] Largely due to expanded environmental liability exposure and broad interpretations of the term "accident," CGL policies became stingier over time with their

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[89] Again, if monitoring is an issue, insurers could also condition favorable premiums on maintaining a low record of violations of state regulations, which would achieve similar compliance objectives.

[90] Some scholars have argued that the availability of insurance may also improve compensation outcomes by making courts more comfortable with holding companies responsible for the environmental harms caused by their activities (Abraham 2008), making injured parties more likely to sue (Dana and Wiseman 2014), and transfering payment to victims more efficiently (Freeman and Kunreuther 1997).

[91] Abraham (2008) more thoroughly describes the emergence and evolution of CGL policies.

coverage of environmental liability. Basically, environmental liability can attach to injuries or damages that do not manifest until years after the liability-producing accidental pollution release (such as Category III and IV risks to water). The emergence of a "long tail" on claims made it difficult for insurers to predict overall liability (Abraham 2008). CGL policies began to contain a "pollution exclusion" that precludes liability coverage for damages caused by the discharge of pollution unless the discharge was "sudden and accidental." But because courts have allowed unexpected gradual discharge of pollutants to count as "sudden and accidental" discharges, some CGL policies now contain an "absolute pollution exclusion," which removes the "sudden and accidental" exception in total.[92]

Instead of standard-form occurrence-based liability coverage for accidental pollution discharges, operators can purchase specialized policies that cover liability and cleanup costs associated with pollution discharges. These policies are generally referred to as environmental impairment liability (EIL) insurance policies, and there are oil-and-gas specific EIL policies. These specialized policies cover bodily injury, property damage, and remediation expenses, but they often only provide coverage on a "claims-made" basis, meaning that the policies only cover damages from qualifying pollution events that are claimed during the policy period. For example, a specialized EIL policy would cover damages from the contamination of a private water well by fracking wastewater that leaked from a storage container located on a well site—if the claim for the loss was made and reported during the policy period. The claims-based coverage cut

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[92] The stingiest CGL policies include a "total pollution exclusion." IRMI.com, an insurance resource, provides more detailed information about these policies and exclusions, http://www.irmi.com.

off the difficult-to-insure long tail, providing no coverage for later liability for long-latency harms from a pollution release that occurred during the policy period.

These policy coverage descriptions suggest that traditional CGL policies are likely to cover Category I and III risks as long as the policies do not contain an absolute pollution exclusion.[93] Once the CGL contains an absolute pollution exclusion, however, the policy might not cover any water-contamination risks. Specialized EIL policies, in contrast, are likely to cover Category I and II risks, but they are unlikely to cover any risks with latent harms[94] and any risks that involve the possibility of delayed detection. Table 15 summarizes the possible coverage.

Broadly speaking, insurance is available to cover some water-contamination risks of drilling and, especially, fracking. Most drilling operators carry CGL policies, but not many purchase additional EIL insurance and those who do purchase such coverage may not purchase enough coverage.[95] Of course, an operator can choose not to purchase insurance and self-insure against all environmental risks. When an operator is large enough, self-insurance is a viable strategy. Self-insurance, however, is unlikely to be a viable strategy for small- to medium-sized operators given that damages from water-contamination events are in the millions. And, reports suggest that smaller operators are, on average, more likely to incur violations during drilling.[96]

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[93] It is possible, however, that some policies are written to exclude some of the risks of fracking, such as damages stemming from contamination by fracking fluid.

[94] Unless insurers are made liable for medical monitoring expenses for potential future manifestations of disease or illness when the claim is made at the time of the accident.

[95] One insurer estimates that only about thirty to forty percent of oil-and-gas companies buy EIL policies. Douglas McLeod. 2013. “Insurance Coverage Options for Fracking Risks are Limited.” *Business Insurance*, February 24.

[96] Daniel Gilbert and Russell Gold. 2013. “As Big Drillers Move In, Safety Goes Up.” *Wall Street Journal*, April 1.

Mandating Insurance

Before mandating any form of liability insurance, state regulators should examine why operators are not purchasing insurance in their area. It could be that operators are not being held liable for immediate environmental harms in tort, which could suggest problems in the state's tort liability regime that should be separately addressed. As discussed previously, causation hurdles in tort make it challenging for plaintiffs to prove their cases—that drilling activities caused their damages. Operators will not choose to pay premiums for coverage that they do not think that they will use.

It could also be that operators are not willing to purchase insurance because premiums are too high relative to expected damages. Freeman and Kunreuther (1997) document that the ambiguity of risks plays a role when insurers decide what premium to charge; more ambiguous risks lead to higher premiums. One source of risk ambiguity could be outstanding liability uncertainty.[97] The liability uncertainty may be highest in the Marcellus shale area because the case law is particularly undeveloped and the extent of damages may be high as the area is heavily populated and many people rely on private water wells for drinking water.[98] There are a few fracking-related water-contamination cases making their way through the courts, but none have been decided yet. If this is the source of high premiums, state legislators could reduce premiums by reducing some of the tort liability uncertainty through tort reforms that clarify causation and outline compensable damages.

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[97] Another source of ambiguity is the scientific uncertainty surrounding some risk pathways. This uncertainty is most prevalent for Category III and IV risks, and I do not advocate that operators be required to purchase insurance to cover corresponding harms of these risks.

[98] This may be why only one insurer is known to provide EIL coverage in the Marcellus shale area (Ironshore), and based on my conversations with insurers, its premiums are expensive.

In addition, the lack of a set of operating practices that maximize the net benefits of shale development could contribute to ambiguity. For example, the senior vice president of one energy insurance provider, Energi, Inc., has called for a "more consistent, visible and effective set of best operating practices" and, in particular, "common agreement among states on a [set of] best practices" to improve insurance availability.[99] Again, here, the development of net beneficial regulations could reduce these concerns.

Finally, the insurance market might not function well on its own due to concerns about adverse selection. Adverse selection would occur when insurers could not distinguish between operators that present a high risk of loss and those who present a low risk of loss, offering both groups insurance coverage at the same price. The riskier operators would be more likely to purchase the insurance, which might cause the insurer to raise the price, thus further reducing the probability that less risky firms would purchase insurance. This could lead to a situation where premiums are high, and many operators do not purchase insurance.

Once it is clear that the regulatory and tort systems are able to support the provision and purchase of insurance, states should consider mandating EIL insurance coverage for operators that drill within their jurisdictions. Insurance mandates have two direct benefits: they eliminate adverse selection, and they block judgment-proof injurers from engaging in the activity. Once all firms are required to purchase insurance, the insurer will no longer have to worry about less risky operators opting out. And, if states require the purchase of sufficient coverage, then only operators able to afford to pay out expected damages will remain.

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[99] Peter Behr. 2013. "Insurance Issues Loom Over Shale Gas Development." *E&E EnergyWire*, August 1.

So far, not many jurisdictions require insurance for oil-and-gas operators.[100] And, when they do, state and local governments also vary in the amount of coverage that they mandate and typically only mandate CGL insurance, which could have several pollution exceptions. Operators are required to purchase EIL coverage in only one state, Maryland, which does not yet allow fracking.[101] Maryland requires coverage of at least $1 million to cover bodily injury, property damage, and natural resource damage, which includes the costs of cleanup and remediation caused by the discharge of pollutants. The state also mandates that the insurance be maintained for five years after the well has been sealed and plugged and the site has been reclaimed.

Under an economic framework, variations in the amount of coverage may be desirable as different areas may have different expected damages from accidental pollution discharges. But, all states should mandate EIL insurance coverage that covers immediate injury, property, and cleanup costs from both accidental sudden and gradual releases of pollution—that is, Category I and II risks to water. Policies should continue to only cover claims made during the policy period, perhaps within some time window of the incident responsible for the pollution release. Policies would then incentivize operators to immediately report spills or leaks to ensure that any resulting damages are covered by their insurance. Early discovery of pollution releases would mitigate environmental damages and minimize remedial costs.

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[100] Municipalities such Arlington and Fort Worth, Texas, and some states, including Colorado, Idaho, Maryland, New jersey, Ohio, and Oregon, require insurance coverage. Dana and Wiseman (2014) provide a more comprehensive overview of local and state efforts.

[101] Md. Code Ann., Envir. § 14-111(7) (2013).

Operators should not be required to purchase insurance coverage that would cover Category III and IV harms.[102] Few insurers would be willing to underwrite such comprehensive policies given the uncertainty associated with latent harms, and the inclusion of these harms in coverage would drive up premiums. Dana and Wiseman (2014) argue that "insurance markets have consistently produced adequate insurance capacity once a mandate was enacted" despite risk uncertainty and predictions to the contrary. To support their claims, they refer to the $1.5 billion in insurance capacity generated in response to a de facto insurance mandate on offshore oil shippers and drilling operators.

But, previous cases where insurers supplied enough insurance capacity to satisfy demand despite uncertain environmental liability were characterized by significant tort and regulatory reforms. Referring to Dana and Wiseman's example, the federal government does require offshore oil shippers and drilling operators to prove financial responsibility for removal costs from oil spills,[103] which operators can satisfy by demonstrating sufficient insurance coverage (Abraham 2011). But, the federal liability scheme[104] for offshore operators imposes a maximum liability cap that depends on the facility, typically removal costs plus $75 million,[105] and requires operators to prove financial responsibility sufficient to meet maximum liability.[106] These caps make it easier

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[102] An exception to this is the previously discussed requirement for operators to post assurance bonds to ensure proper well abandonment (Dana and Wiseman 2014). Once the operator proves that it has properly plugged and sealed the well, the operator may retrieve the bond that it posted.

[103] 33 U.S.C. §§ 2701–61.

[104] Offshore drilling is subject to liability and regulatory provisions under the Clean Water Act § 311, 33 U.S.C. § 1321, and the Oil Pollution Act, 33 U.S.C. §§ 2701–61.

[105] This is the liability cap for an offshore facility except a deepwater port. 33 U.S.C. § 2704(a)(3).

[106] *Id.* § 2716. Of course, as the 2010 BP *Deepwater Horizon* disaster demonstrated, these insurance limits can be far too low to compensate victims and remediate the environment in the case of large spills. I discuss the possibility of catastrophic damages next.

for insurers to price premiums for uncertain risk pathways.[107] Unless state legislatures set a liability cap for damages from accidental pollution releases, then it is not likely that many insurers will offer to insure operators against liability for later-manifested harms.

Thus far, however, the analysis in this chapter has not considered the possibility of catastrophic damages from shale development. This is partly because the findings in Chapter I suggest that average impacts are small. The focus of this chapter was then to develop a comprehensive regulatory system that responds to all risk pathways. But, if a low-probability risk of catastrophic damages manifests, the injurer is unlikely to have the financial resources to pay for damages even in a regulatory system that requires operators to carry insurance that would cover expected damages.

States concerned about low-probability catastrophic damages of shale development could look to the proposals for creating a system to cover catastrophic damages from offshore drilling accidents; many of these proposals were generated in the wake of the 2010 BP *Deepwater Horizon* disaster that highlighted the inadequacy of the regulatory regime for offshore drilling in dealing with spills of that magnitude. Insights from these proposals could be applied to onshore shale development.[108] For example, Viscusi and Zeckhauser (2011) recommend a "two-tier" liability system that includes regulatory, tort, and insurance interventions. Specifically, they recommend combining a high individual tort liability cap for operators that would cover damages from a large spill with an ex ante tax on all operators. The taxes would be paid into a fund that would be

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[107] In addition, the federal government has mandated insurance for owners of nuclear plants, but the insurance requirements were also passed with limits on the extent of private liability. Nuclear Regulatory Commission, Fact Sheet, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/funds-fs.html.

[108] Note that worst-case scenario damages would be different than those for offshore drilling, and these damages could vary by shale formation.

used to cover damages that are in excess of the individual liability cap.[109] Operators would also need to prove financial responsibility by obtaining liability insurance sufficient to cover damages up to the individual liability cap.[110] Hence, if shale development is characterized by the possibility of catastrophic damages, then state regulators may similarly consider setting much higher insurance coverage requirements than otherwise suggested by average damage estimates and augmenting available funds with an ex ante tax.[111]

Conclusion

In Chapters I and II, I find that perceived risks to water from drilling activities can lower property values for vulnerable properties and lead to outright bans on shale development. To help manage the externalities associated with shale development, governments can deploy three tools—regulation, liability rules, and insurance mandates. In this chapter, I have discussed how these systems interact with each other, suggesting that different combinations of these tools can be used to manage harms from different risk categories. I conclude by explicitly outlining the tools that regulators could prioritize for each risk category. These priorities are summarized in Table 16.

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[109] Financing part of the fund with a percentage of fines collected each year could also add a fault element to fund payment. Those responsible for the worst violations would contribute more money to the fund.

[110] Similarly, Cohen et al. (2011) propose setting a liability cap for each well equal to the worst-case social costs of a spill and requiring insurance up to the cap, though Abraham (2011) points out that third-party insurers may be unable to provide that much coverage.

[111] Alternatively, states could require all operators to maintain separate, additional insurance coverage that would be activated should any operator cause catastrophic damages above the individual liability cap. For example, claims resulting from nuclear accidents are covered under the Price-Anderson Act, which both mandates an individual “first tier” level of insurance for owners of nuclear power plants and generates a plan for obtaining additional funds from insurers in the case of severe accidents. Nuclear Regulatory Commission, Fact Sheet, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/funds-fs.html.

Category I and II risks manifest in immediate harms to water sources. These risks are not very different from the risks to water presented by all onshore drilling activities, not just shale development. Regulators should require operators to adopt all risk-mitigating operating practices that generate net benefits. Strict liability for drilling harms will also motivate operators to adopt these practices, especially if legislative and regulatory interventions facilitate recovery for actual drilling-related harms. Mandatory insurance coverage for Category I and II risks will then guarantee that only operators that are able to pay for expected immediate harms (reasonable care notwithstanding) engage in drilling activities. Net beneficial regulations, an adequate enforcement system, and robust tort litigation will ensure that operators continue to adopt all net-beneficial risk mitigation operating practices.

States should recognize that this regulatory strategy, however, is unlikely to address those Category III and IV risks that are characterized by uncertain pathways and latent harms. Regulators should implement research strategies now to learn more about these risks. By being proactive, regulators can amass scientific data and update regulations in a timely manner and in an appropriate way given the information. Tort litigation can still function as a backstop motivating force. If governments are concerned about having money available to address these latent harms in the future, then governments could apply a portion of regulatory fines to form a fund. This fund could be used in the future to remediate the environment when those responsible for latent-manifesting contamination are unable to pay.[112] Financing the fund with a percentage of fines collected each year would also add a fault element; those responsible for the worst violations would contribute a larger amount of money to the fund.

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[112] Ideally, health insurance would pay for any latent health risks to individuals.

Both Pennsylvania and New York have been proactive in developing new regulatory schemes to accommodate shale development while addressing environmental risks. In February 2012, Pennsylvania passed Act 13,[113] a law that strengthened many environmental protections for water sources by increasing setback requirements and establishing the presumption of liability for water contamination for operators of unconventional wells. Meanwhile, New York has prohibited shale development since 2008 to allow the state to develop comprehensive shale regulations. If the final SGEIS resembles the revised draft SGEIS published in September 2011, then New York will have the most comprehensive shale regulations in the country (Richardson et al. 2013). Pennsylvania's regulatory changes may mitigate property-value losses going forward, and once finalized, New York's regulations may lower the incidence of local bans.

But, gaps still remain. Neither state requires insurance coverage, and neither state makes provisions for research into uncertain risk pathways. It is also not evident whether the current set of regulations in either state is net beneficial. By applying insights from this chapter, states such as Pennsylvania and New York could ensure that all types of risks to water are managed through regulation, litigation, and insurance. When deployed effectively, these three tools will responsibly facilitate shale development by creating incentives for optimal activity levels, acceptable risk-taking, and comprehensive environmental protection.

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[113] 58 Pa. Cons. Stat. §§ 2301–3504 (2013).

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Table 14. A Typology of Water-Contamination Harms from Shale Development

Incident Type Harm Discovery	Sudden	Gradual
Immediate	Category I: A spill, discharge, or blowout event that contaminates nearby soil or water Pathways: Some fracturing process (improper well casing); blowouts; some storage/transport; some wastewater disposal	Category II: A slowly leaking on-site waste storage pit that contaminates nearby soil or water Pathways: some fracturing; storage; some disposal
Delayed (latent harms)	Category III: Any spill, discharge, or blowout found to generate latent harms Pathways: Fracking fluid flowing into natural fault lines in the local geology; any blowouts, spills or leaks linked to latent health harms	Category IV: Leaking pits, disposal wells, or abandoned wells that generate later harms Pathways: Unplugged abandoned wells with later leaks; later leaking disposal wells; improper wastewater disposal linked to latent health harms; gas seeping into natural fault lines in the local geology

Table 15. Insurance Coverage for Risk Categories by Insurance Plan

	Category I	Category II	Category III	Category IV
CGL	YES	MAYBE	YES	MAYBE
CGL with pollution exclusion	YES	NO	YES	NO
CGL with absolute pollution exclusion	NO	NO	NO	NO
EIL	YES	YES	NO	NO

Notes. CGL refers to commercial general liability insurance plans. EIL refers to environmental impairment liability insurance plans. A “pollution exclusion” precludes liability coverage for damages caused by the discharge of pollution unless the discharge was “sudden and accidental.” An “absolute pollution exclusion” removes the “sudden and accidental” exception in total.

Table 16. Prioritizing Regulatory Tools By Risk Category

	Category I	Category II	Category III	Category IV
Net-Beneficial Regulation	YES	YES	NO	Some: YES
Research Investments	NO	NO	YES	YES
Tort Liability Standards	YES	YES	YES	YES
Insurance Mandates (EIL)	YES	YES	NO	NO
Assurance Bonds	NO	NO	YES	YES

Notes. EIL refers to environmental impairment liability insurance plans. See text for details.

APPENDIX A

APPENDIX TO CHAPTER I

In this Appendix, I provide the results of a series of robustness checks. In general, my qualitative results do not change when I alter the spatial and temporal definitions of my variables of interest, use indicator variables, analyze only recent environmental health and safety (EH&S) violations, include well investigations, and limit my analysis to gas wells. I also present limited evidence that the results for Washington County, Pennsylvania may be generalizable to other similar areas facing extensive shale development.

Spatial and Temporal Robustness Checks

First, I analyze the sensitivity of my results by varying the spatial and temporal dimensions of the nearby-well variables. Specifically, I allow the distance buffer around properties to vary between 0.75 and 2 miles, and I look at all nearby wells drilled prior to the property's sale, only wells drilled within the two years before the sale, and only wells drilled within one year before the sale. Table 17 summarizes the coefficients of interest for these regressions. The coefficients are similar and often statistically significant, especially the coefficient on the interaction term between violations and wells. To help demonstrate overall patterns, I graph these coefficients in Figure 1. The coefficients tend to be largest in magnitude when I use well counts within 0.75 miles of each property and especially for wells drilled within the year prior to the property's sale. These results suggest that closer and more recently drilled horizontal wells have the greatest effects on a property's value.

Indicator Variables of Interest

In Table 18 through Table 20, I modify my coefficients of interest by generating indicator variables. First, I generate indicator well variables. For example, my horizontal well dummy variable is equal to one if there is at least one horizontal well within a mile of the property and zero otherwise. Next, I generate indicator violations variables. For example, I create an indicator variable equal to one if the property sold after above-average numbers of well violations in the previous six months and zero otherwise (using the county's own well-violations sample average). I also generate interactions between these variables and other variables of interests.

Table 18 presents the main results using well indicator variables. I find that having at least one horizontal well within a mile raises property values by between 10 and 20 percent. This estimated effect is much higher than the effect I estimated using well count variables, likely because most properties, if they have any nearby horizontal well, have multiple nearby horizontal wells. Specifically, properties with at least one horizontal well within a mile have on average five horizontal wells within a mile. I also find that, at the average number of county-level environmental violations, having a horizontal well within a mile decreases a property's value by about 6 percent.

In Table 19, I summarize the results when recent violations in the county are compared to the county's own well-violations average. In this way, I test for whether noticing violations above the expected number of violations drives the results. In the case of above average numbers of EH&S violations leading up to the sale, a property loses about 1.4 percent of its value for each additional horizontal well within a mile. This effect reduces the direct benefit of an additional nearby horizontal well to about a 0.5 percent increase in property value.

Finally, in Table 20, I use the violations indicator variables together with the well indicator variables. Again, the effects are the same in sign, but much larger in magnitude. Above-average EH&S violations at the county level reduce the benefit of having a nearby horizontal well by about half.

I also run regressions that approximate the nearest-neighbor matching runs. Because the matching estimator requires a binary treatment variable, the results should be compared to my results when I use the horizontal wells indicator variable. In Table 21, I demonstrate that my results are similar to the results generated using the matching estimator.

Recent Environmental, Health, and Safety Violations

In my model, individuals pay attention to information on recent well violations. At first blush, however, it is not obvious how recent these violations should be. After a violation is discovered, it must be posted on the PADEP website. In addition, homeowners and homebuyers need time to view and process the information. Because most homebuyers take a few months to search for a new home, I use the number of violations in the six months prior to each property's sale as a reasonable time window during which homebuyers may view information on well violations.

In this robustness test, I generate variables equal to the number of violations that occurred in the three months prior to each property's sale. Table 22 summarizes these results. The pattern is similar to the pattern summarized in Table 3 in the main text. As before, the results demonstrate that EH&S shale violations have the strongest effects on property values for properties with nearby horizontal wells. This result is consistent with the idea that individuals derive more risk-relevant informational content from these violations than from EH&S violations at conventional wells. The coefficients on other variables do not change.

Well Investigations

As an additional robustness check, I control for the number of county-level well investigations in the six months prior to each property's sale in Table 23. This test serves to rule out potential omitted variable bias of the following form: the number of well violations is correlated with the number of wells in the county, and the volume of drilling activity might affect property values. Well investigations are a good control because, while they are correlated with county well activity (even more so than are well violations), well investigations tend not to offer much risk information. Most well investigations are scheduled or surprise visits.[114] Controlling for the number of well

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[114] Some investigations, however, are initiated in response to reported spills and other possible violations. If anything, this suggests that total investigations may provide some, albeit small, risk information.

investigations has little effect on the size and statistical significance of the coefficient on the interaction between horizontal wells and shale well violations, suggesting that county-level well activity does not drive the estimated effect. The coefficients on other variables of interest do not change much, but they lose statistical significance. The coefficient on investigations is small, positive, and statistically significant, suggesting that some of the positive effect of nearby horizontal wells is due to positive economic effects on the county level from drilling activity.

Effect of Gas Wells

Because most shale development involves natural gas extraction, I test whether my effects are driven by horizontal gas wells. Table 24 summarizes these results. As expected, I find that my results are driven by nearby horizontal gas wells. I do not limit to gas wells in my main specification, however, because I hesitate to assume that homeowners and homebuyers are aware whether a nearby well is a gas, oil, or other well. In contrast, there are many reasons to suspect that residents can distinguish between nearby vertical and horizontal wells (I summarize these reasons in my main discussion).

Endogeneity Concerns

I run a falsification test to determine whether it is likely that operators choose to drill where property values are lower and whether my controls (city and school district fixed effects as well as property and tract characteristics) mitigate any such findings. In my data, the first nearby horizontal wells appear in Washington County in 2007. Although oil and gas companies can lease mineral rights for a number of years before any drilling begins, the years 2004 and 2005 are before the big shale revolution in Pennsylvania and likely before companies were buying up leases in droves. I match each property sold in 2004 and 2005 with the number of horizontal wells that will be drilled within a mile of it in the future, and I also generate an indicator variable equal to one if any horizontal well will be drilled within a mile of the property in the future. I use these variables to see if future horizontal wells are linked to any property-value effects for properties sold in 2004 and 2005.

Table 25 summarizes these results. In uncontrolled regressions, I do find evidence of possible endogeneity when I group properties sold in 2004 and in 2005. Properties that will have at least one horizontal well in the future (2007 and onward) sold for about 10 percent less than other properties in 2004 and 2005, without controlling for any other property or neighborhood characteristics. When I control for property and tract characteristics and use city, school district, and year fixed effects as in my main regression, however, I do not find any statistically significant difference in sale prices in 2004 and 2005. That is, the sale price of properties that will have at least one horizontal well in the future is not statistically significantly different from the sale price of similar properties that will not have a well in the future.

Generalizability of Results

I focus on Washington County in particular because it is the highest shale-producing Pennsylvania county for which I have property sales data. But, it is worthwhile to consider whether the results for Washington County, Pennsylvania are generalizable to other counties. Residents of Washington County have experience with conventional oil and gas development, which may be why residents do not seek out information about vertical well risks. The county also has experienced a significant amount of shale development to make estimation of specific results for horizontal wells meaningful.

In order to lend support to this theory, I test my hypotheses on data from Westmoreland County, Pennsylvania. Westmoreland County contributes about three percent of total Pennsylvania shale production, which is less than the nine percent contributed by Washington County. Thus, the county has fewer numbers of shale wells. The county is also more populous (with 366,000 residents compared to Washington County's 210,000) and more experience with conventional wells. Table 26 contains more summary statistics for Westmoreland County. As expected, properties in Westmoreland County have a much higher number of wells within one mile (11.97) due to the history of conventional drilling in that county, but they have fewer horizontal wells within one mile on average (0.02). I also did not have data on some property characteristics such as the numbers of bedrooms and bathrooms or the presence of a garage, fireplace, or pool.

Despite these differences, I find similar results for Westmoreland County, suggesting that the two counties are similar enough on relevant dimensions, although the results for Westmoreland County are not statistically significant. Table 27 summarizes these results using my main specification. I find that horizontal wells may also drive resident concerns. In addition, I find that higher numbers of recent EH&S violations are associated with property-value losses for properties with nearby horizontal wells. As before for Washington County, I vary the spatial and temporal definitions of my variables of interest. Table 28 provides the coefficients of interest from these regressions. The results are sensitive to these variations, and the coefficients are often not statistically significant. The few statistically significant coefficients on the interaction between horizontal wells and various violations information, however, have the predicted sign. Figure 2 graphs these coefficients of interest. The resulting pattern is similar to the pattern revealed in Figure 1, which graphs Washington County's coefficients of interest.

These results suggest that residents of other counties with a history of conventional drilling that are experiencing rapid shale development, perhaps across states, may respond similarly to perceived groundwater risks and information on well violations. For example, this might include areas in Alabama, Louisiana, and Texas. Future research could determine whether results are similar in counties that are entirely new to drilling.

Table 17. Spatial and Temporal Robustness Checks on Coefficients of Interest, Washington County.

A. Horizontal Well Count (Table 2, Equation 4)

	Temporal Variation		
Spatial Variation	All horiz. wells drilled before sale	Horiz. wells drilled 2yrs before sale	Horiz. wells drilled 1yr before sale
2 miles	0.009***	0.011**	0.019**
	(0.003)	(0.005)	(0.008)
1 mile	0.020**	0.023*	0.013
	(0.010)	(0.013)	(0.019)
0.75 miles	0.023**	0.028**	0.049*
	(0.011)	(0.013)	(0.029)

B. Private Water Well and Horizontal Well Interactions (Table 2, Equation 4)

	Temporal Variation		
Spatial Variation	All horiz. wells drilled before sale	Horiz. wells drilled 2yrs before sale	Horiz. wells drilled 1yr before sale
2 miles	-0.005	-0.004	-0.005
	(0.004)	(0.005)	(0.006)
1 mile	-0.014*	-0.018*	-0.012
	(0.009)	(0.011)	(0.015)
0.75 miles	-0.012	-0.016	-0.026
	(0.010)	(0.012)	(0.023)

C. EH&S Shale Violations and Horizontal Well Interactions (Table 2, Equation 4)

	Temporal Variation		
Spatial Variation	All horiz. wells drilled before sale	Horiz. wells drilled 2yrs before sale	Horiz. wells drilled 1yr before sale
2 miles	-0.0003***	-0.0004***	-0.0008***
	(0.0001)	(0.0001)	(0.0002)
1 mile	-0.0004**	-0.0004	-0.0003
	(0.0002)	(0.0003)	(0.0005)
0.75 miles	-0.0007***	-0.0008**	-0.0018**
	(0.0003)	(0.0003)	(0.0007)

D. EH&S Violations and Horizontal Well Interactions

	Temporal Variation		
Spatial Variation	All horiz. wells drilled before sale	Horiz. wells drilled 2yrs before sale	Horiz. wells drilled 1yr before sale
2 miles	-0.0003***	-0.0004**	-0.0005***
	(0.0001)	(0.0002)	(0.0002)
1 mile	-0.0004**	-0.0004	-0.0001
	(0.0002)	(0.0003)	(0.0004)
0.75 miles	-0.0007**	-0.0007*	-0.0015**
	(0.0003)	(0.0004)	(0.0007)

Notes. See graphical representation in Figure 1.

Table 18. Results using Well Indicator Variables.

	Natural Log of Sale Price (2012$)			
Variables	(1)	(2)	(3)	(4)
Vertical wells w/in 1 mile indicator (0/1) (Vertical dummy)	0.039	0.052	0.058	0.073
	(0.058)	(0.062)	(0.056)	(0.060)
Horizontal wells w/in 1 mile indicator (0/1) (Horizontal dummy)	0.069 (0.046)	0.095* (0.055)	0.163** (0.068)	0.185** (0.071)
Vertical dummy x Private well water		-0.102		-0.105
		(0.072)		(0.073)
Horizontal dummy x Private well water		-0.114 (0.102)		-0.110 (0.105)
EH&S violations			0.002	0.002
			(0.001)	(0.001)
Vertical dummy x EH&S violations			-0.001	-0.001
			(0.001)	(0.001)
Horizontal dummy x EH&S violations			-0.003** (0.001)	-0.003** (0.002)
Private well water	0.095*	0.187**	0.097**	0.191**
	(0.048)	(0.083)	(0.047)	(0.084)
Property Characteristics	Yes	Yes	Yes	Yes
Census Tract Characteristics	Yes	Yes	Yes	Yes
Year, City, & School District Controls	Yes	Yes	Yes	Yes
Constant	11.220***	11.267***	11.203***	11.248***
	(0.273)	(0.276)	(0.284)	(0.287)
Observations	21,987	21,987	21,987	21,987
Adjusted R-squared	0.613	0.613	0.613	0.613

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicator for property or tract characteristics are included in all regressions. Property and census tract characteristics include the variables presented in Table 2. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 19. Results using Violations Indicator Variables.

	Natural Log of Sale Price (2012$)	
Variables	(1)	(2)
Vertical wells	0.003	0.003
	(0.004)	(0.004)
Horizontal wells	0.019**	0.020**
	(0.008)	(0.008)
Vertical wells x Private well water	-0.005	-0.005
	(0.004)	(0.004)
Horizontal wells x Private well water	-0.014*	-0.013
	(0.008)	(0.008)
EH&S violations above county average, 6mo before sale (0/1)	-0.025	
	(0.022)	
Vertical wells x Above-average EH&S violations	-0.001	
	(0.002)	
Horizontal wells x Above-average EH&S violations	-0.014***	
	(0.004)	
EH&S violations on shale wells above average (0/1)		-0.026
		(0.025)
Vertical wells x Above-average EH&S shale violations		-0.001
		(0.003)
Horizontal wells x Above-avg EH&S shale violations		-0.015***
		(0.005)
EH&S violations on conventional wells above average (0/1)		-0.036
		(0.031)
Vertical wells x Above-average EH&S conventional violations		0.002
		(0.003)
Horizontal wells x Above-avg EH&S conventional violations		-0.009
		(0.007)
Private well water	0.126**	0.126**
	(0.055)	(0.055)
Property Characteristics	Yes	Yes
Census Tract Characteristics	Yes	Yes
Year, City, & School District Controls	Yes	Yes
Constant	11.259***	11.743***
	(0.253)	(0.367)
Observations	21,987	21,987
Adjusted R-squared	0.613	0.615

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicator for property or tract characteristics are included in all regressions. Property and census tract characteristics include the variables presented in Table 2. *** p<0.01, ** p<0.05, * p<0.1.

Table 20. Results using Well and Violations Indicator Variables.

	Natural Log of Sale Price (2012$)	
Variables	(1)	(2)
Vertical dummy	0.064	0.066
	(0.059)	(0.058)
Horizontal dummy	0.154**	0.173***
	(0.059)	(0.058)
Vertical dummy x Private well water	-0.104	-0.104
	(0.072)	(0.072)
Horizontal dummy x Private well water	-0.114	-0.112
	(0.104)	(0.105)
EH&S violations above county average, 6mo before sale (0/1)	-0.002 (0.060)	
Vertical dummy x Above-avg EH&S violations	-0.031	
	(0.067)	
Horizontal dummy x Above-avg EH&S violations	-0.085*	
	(0.044)	
EH&S violations on shale wells above average (0/1)		0.001
		(0.068)
Vertical dummy x Above-avg EH&S shale violations		-0.037
		(0.073)
Horizontal dummy x Above-avg EH&S shale viols		-0.107**
		(0.053)
EH&S violations on conventional wells above average (0/1)		-0.048 (0.052)
Vertical dummy x Above-avg EH&S conventional violations		0.027 (0.053)
Horizontal dummy x Above-avg EH&S conventional viols		-0.028 (0.063)
Private well water	0.189**	0.190**
	(0.083)	(0.083)
Property Characteristics	Yes	Yes
Census Tract Characteristics	Yes	Yes
Year, City, & School District Controls	Yes	Yes
Constant	11.286***	11.778***
	(0.280)	(0.390)
Observations	21,987	21,987
Adjusted R-squared	0.613	0.615

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicator for property or tract characteristics are included in all regressions. Property and census tract characteristics include the variables presented in Table 2. *** p<0.01, ** p<0.05, * p<0.1.

Table 21. Results Approximating the Matching Estimator.

	Natural Log of Sale Price (2012$)		
Variables	(1)	(2)	(3)
Vertical wells	0.002	0.002	0.002
	(0.003)	(0.004)	(0.003)
Horizontal dummy	0.072	0.089*	0.140**
	(0.044)	(0.052)	(0.054)
Vertical wells x Private well water		-0.005	
		(0.004)	
Horizontal dummy x Private well water		-0.104	
		(0.099)	
EH&S violations on shale wells above average (0/1)			-0.033 (0.023)
Vertical wells x Above-average EH&S shale violations			-0.001 (0.002)
Horizontal dummy x Above-average EH&S shale violations			-0.098* (0.052)
Private well water		0.126**	0.097**
		(0.056)	(0.047)
Well investigations			2.9e-4***
			(9.3e-5)
Property Characteristics	Yes	Yes	Yes
Census Tract Characteristics	Yes	Yes	Yes
Year, City, & School District Controls	Yes	Yes	Yes
Constant	11.640***	11.708***	11.789***
	(0.381)	(0.370)	(0.380)
Observations	21,987	21,987	21,987
Adjusted R-squared	0.613	0.613	0.613

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicator for property or tract characteristics are included in all regressions. Property and census tract characteristics include the variables presented in Table 2. *** p<0.01, ** p<0.05, * p<0.1.

Table 22. Shale Versus Conventional Environmental, Health, and Safety Violations, Three Months Prior to Sale.

	Natural Log of Sale Price (2012$)	
Variables	(1)	(2)
Vertical wells	0.003	0.003
	(0.004)	(0.004)
Horizontal wells	0.019**	0.018**
	(0.009)	(0.009)
Vertical wells x Private well water	-0.005	-0.005
	(0.004)	(0.004)
Horizontal wells x Private well water	-0.014*	-0.014
	(0.008)	(0.008)
EH&S violations, 3 months	-2.4e-4	
	(7.4e-4)	
Vertical wells x EH&S violations, 3 months	-4.7e-6	
	(8.2e-5)	
Horizontal wells x EH&S violations, 3 months	-7.7e-4***	
	(2.5e-4)	
EH&S shale violations, 3 months		-6.0e-4
		(0.001)
Vertical wells x EH&S shale violations, 3 months		-3.5e-5
		(1.7e-4)
Horizontal wells x EH&S shale violations, 3 months		-9.1e-4*** (2.7e-4)
EH&S conventional violations, 3 months		2.1e-4
		(0.001)
Vertical wells x EH&S conventional violations, 3 months		2.0e-5 (1.2e-4)
Horizontal wells x EH&S conventional violations, 3 months		0.001 (0.001)
Private well water	0.126**	0.126**
	(0.055)	(0.055)
Property Characteristics	Yes	Yes
Census Tract Characteristics	Yes	Yes
Year, City, & School District Controls	Yes	Yes
Constant	9.943***	11.711***
	(0.222)	(0.370)
Observations	21,987	21,987
Adjusted R-squared	0.613	0.615

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicator for property or tract characteristics are included in all regressions. Property and census tract characteristics include the variables presented in Table 2. *** p<0.01, ** p<0.05, * p<0.1.

Table 23. Controls for County-Level Investigations.

Variables	Natural Log of Sale Price (2012$) (1)
Vertical wells	0.003
	(0.004)
Horizontal wells	0.030
	(0.037)
Vertical wells x Private well water	-0.005
	(0.004)
Horizontal wells x Private well water	-0.014
	(0.009)
EH&S shale violations	-3.8e-4
	(9.0e-4)
Vertical wells x EH&S shale violations	-2.8e-5
	(8.1e-5)
Horizontal wells x EH&S shale violations	-4.4e-4*
	(2.6e-4)
Well investigations	2.6e-4***
	(9.8e-5)
Vertical wells x Well investigations	4.3e-7
	(4.6e-6)
Horizontal wells x Well investigations	-1.4e-5
	(3.9e-5)
Private well water	0.126**
	(0.055)
Property Characteristics	Yes
Census Tract Characteristics	Yes
Year, City, & School District Controls	Yes
Constant	11.786***
	(0.368)
Observations	21,987
Adjusted R-squared	0.613

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicators for property or tract characteristics are included in all regressions. Property and census tract characteristics include the variables presented in Table 2. *** p<0.01, ** p<0.05, * p<0.1.

Table 24. Results using Gas Wells.

Variables	Natural Log of Sale Price (2012$) (1)
Vertical gas wells	0.010*
	(0.006)
Horizontal gas wells	0.021**
	(0.010)
Other wells	-0.005
	(0.003)
Vertical gas wells x Private well water	-0.003
	(0.005)
Horizontal gas wells x Private well water	-0.016*
	(0.009)
Other wells x Private well water	-0.004
	(0.004)
EH&S shale violations	0.001
	(0.001)
Vertical gas wells x EH&S shale violations	-1.4e-5
	(1.2e-4)
Horizontal gas wells x EH&S shale violations	-4.0e-4*
	(2.0e-4)
Other wells x EH&S shale violations	-1.1e-4
	(7.5e-5)
Private well water	0.110*
	(0.058)
Property Characteristics	Yes
Census Tract Characteristics	Yes
Year, City, & School District Controls	Yes
Constant	11.220***
	(0.273)
Observations	21,987
Adjusted R-squared	0.613

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicator for property or tract characteristics are included in all regressions. Property and census tract characteristics include the variables presented in Table 2. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 25. Endogeneity Falsification Tests, Washington County.

A. Uncontrolled Regressions

	Natural Log of Sale Price (2012$)			
	Sales in 2004		Sales in 2004 and 2005	
Variables	(1)	(2)	(1)	(2)
Future horizontal wells w/in 1 mile	0.005		-0.001	
	(0.007)		(0.005)	
Future horizontal well w/in 1 mile indicator (0/1)		-0.076		-0.102***
		(0.051)		(0.039)
Constant	11.582***	11.599***	11.594***	11.608***
	(0.021)	(0.021)	(0.015)	(0.015)
Observations	2,836	2,836	5,849	5,849
Adjusted R-squared	-0.000	0.000	-0.000	0.001

Notes. Robust standard errors in parentheses. These regressions have no additional controls. *** p<0.01, ** p<0.05, * p<0.1.

B. Controlled Regressions

	Natural Log of Sale Price (2012$)			
	Sales in 2004		Sales in 2004 and 2005	
Variables	(1)	(2)	(1)	(2)
Future horizontal wells w/in 1 mile	-0.005		-0.007	
	(0.007)		(0.007)	
Future horizontal well w/in 1 mile indicator (0/1)		-0.025		-0.044
		(0.059)		(0.059)
Property Characteristics	Yes	Yes	Yes	Yes
Census Tract Characteristics	Yes	Yes	Yes	Yes
Year, City, & School District Controls	Yes	Yes	Yes	Yes
Constant	11.932***	11.980***	11.431***	11.441***
	(0.423)	(0.424)	(0.400)	(0.407)
Observations	2,831	2,831	5,838	5,838
Adjusted R-squared	0.600	0.600	0.596	0.596

Notes. Robust standard errors in parentheses. These regressions have all of the controls that are included in Table 2. *** p<0.01, ** p<0.05, * p<0.1.

Table 26. Summary Statistics – Westmoreland County, Pennsylvania.

Variables	Mean	Std. Dev.
Property Characteristics		
Sale Price (in year 2012 dollars)	153,423	292,966
Building Age	37.93	35.32
Total Living Area (1,000 square feet)	1.75	2.03
Lot Size (100,000 square feet)	0.42	2.11
Building Sold in Year Built	0.07	0.26
Stories (number)	0.41	0.72
Private Well Water	0.07	0.25
Distance to Pittsburgh (miles)	24.66	8.12
Census Tract Characteristics		
Median Household Income	53,940	16,632
Mean Household Income	66,317	19,233
% Age 25+ w/ High School Degree	39.77	8.34
% Age 25+ w/ Bachelor's Degree	16.67	6.35
% Unemployed	6.45	3.26
% Poverty	9.71	7.04
% Over 65 Years Old	18.61	3.90
% Under 19 Years Old	22.83	3.81
% Black	2.87	5.91
% Latino	0.87	0.97
Shale Well Proximity		
Distance to closest well (miles)	0.68	1.26
Number of wells within 1 mile	11.97	14.80
Distance to closest horizontal well	1.21	1.67
Number of horizontal wells within 1 mile	0.02	0.25
Shale Well Compliance		
Total well investigations in county, 6 months before sale	596.77	185.07
Total violations in county, 6 months before sale	39.55	25.14
Total EH&S violations in county, 6 months before sale	24.97	19.83
Total EH&S shale violations in county, 6 months before sale	2.49	3.47

Notes. DataQuick did not provide information on the number of bedrooms or bathrooms or the presence of a garage, fireplace, or pool for Westmoreland County.

Table 27. Main Results, Westmoreland County.

Variables	Natural Log of Sale Price (2012$) (1)	(2)
Vertical wells	4.3e-4	2.4e-4
	(0.001)	(0.001)
Horizontal wells	0.003	0.067
	(0.039)	(0.077)
Vertical wells x Private well water		0.003
		(0.003)
Horizontal wells x Private well water		-0.034
		(0.121)
EH&S violations in county		2.7e-4
		(0.001)
Vertical wells x EH&S violations		-1.3e-5
		(3.2e-5)
Horizontal wells x EH&S violations		-0.008
		(0.006)
Private well water	0.137**	0.077
	(0.065)	(0.108)
Building Age	-0.010***	-0.010***
	(0.001)	(0.001)
Total Living Area (1,000 sqft)	0.041**	0.041**
	(0.017)	(0.017)
Building Sold in Year Built	-0.216***	-0.220***
	(0.057)	(0.056)
Lot Size (100,000 sqft)	0.003	0.003
	(0.010)	(0.010)
Distance to Pittsburgh (miles)	0.016	0.017
	(0.011)	(0.011)
Median Household Income	0.004**	0.004**
	(0.002)	(0.002)
% Black	-0.020***	-0.020***
	(0.005)	(0.005)
% Age 25+ w/ High School Degree	-0.010**	-0.009**
	(0.004)	(0.004)
% Unemployed	-0.009	-0.009
	(0.006)	(0.006)
% Under 19 Years Old	0.001	0.001
	(0.004)	(0.004)
Year Controls	Yes	Yes
City Controls	Yes	Yes
School District Controls	Yes	Yes
Constant	10.960***	10.941***
	(0.491)	(0.482)

	Natural Log of Sale Price (2012$)	
Variables	(1)	(2)
Observations	7,893	7,893
Adjusted R-squared	0.406	0.406

Notes. Robust standard errors clustered at the census tract in parentheses. Missing variable indicator for property or tract characteristics are included in all regressions. *** p<0.01, ** p<0.05, * p<0.1.

Table 28. Spatial and Temporal Robustness Checks on Coefficients of Interest, Westmoreland County.

A. Horizontal Well Count (Table 27, Equation 2)

	Temporal Variation		
Spatial Variation	All horiz. wells drilled before sale	Horiz. wells drilled 2yrs before sale	Horiz. wells drilled 1yr before sale
2 miles	-0.009	-0.005	-0.011
	(0.014)	(0.015)	(0.025)
1 mile	0.067	0.066	0.040
	(0.077)	(0.077)	(0.075)
0.75 miles	0.159	0.115	0.269*
	(0.100)	(0.141)	(0.137)

B. Private Water Well and Horizontal Well Interactions (Table 27, Equation 2)

	Temporal Variation		
Spatial Variation	All horiz. wells drilled before sale	Horiz. wells drilled 2yrs before sale	Horiz. wells drilled 1yr before sale
2 miles	-0.020	-0.021	-0.031
	(0.013)	(0.014)	(0.019)
1 mile	-0.034	-0.031	0.106
	(0.121)	(0.118)	(0.110)
0.75 miles	-0.009	-0.084	-0.040
	(0.177)	(0.154)	(0.123)

C. EH&S Violations and Horizontal Well Interactions (Table 27, Equation 2)

	Temporal Variation		
Spatial Variation	All horiz. wells drilled before sale	Horiz. wells drilled 2yrs before sale	Horiz. wells drilled 1yr before sale
2 miles	0.0004	-0.0001	0.0003
	(0.0018)	(0.0018)	(0.0022)
1 mile	-0.0078	-0.0083	-0.0152**
	(0.0055)	(0.0058)	(0.0070)
0.75 miles	-0.0343***	-0.0235**	-0.0396***
	(0.0113)	(0.0111)	(0.0128)

D. EH&S Shale Violations and Horizontal Well Interactions

	Temporal Variation		
Spatial Variation	All horiz. wells drilled before sale	Horiz. wells drilled 2yrs before sale	Horiz. wells drilled 1yr before sale
2 miles	0.0005	-0.0008	-0.0014
	(0.0031)	(0.0031)	(0.0051)
1 mile	0.0029	0.0049	-0.0044
	(0.0074)	(0.0081)	(0.0177)
0.75 miles	-0.0590***	-0.0339	-0.0459*
	(0.0210)	(0.0245)	(0.0250)

Notes. See graphical representation in Figure 2.

Figures

Figure 1. Coefficients of Interest, Washington County.

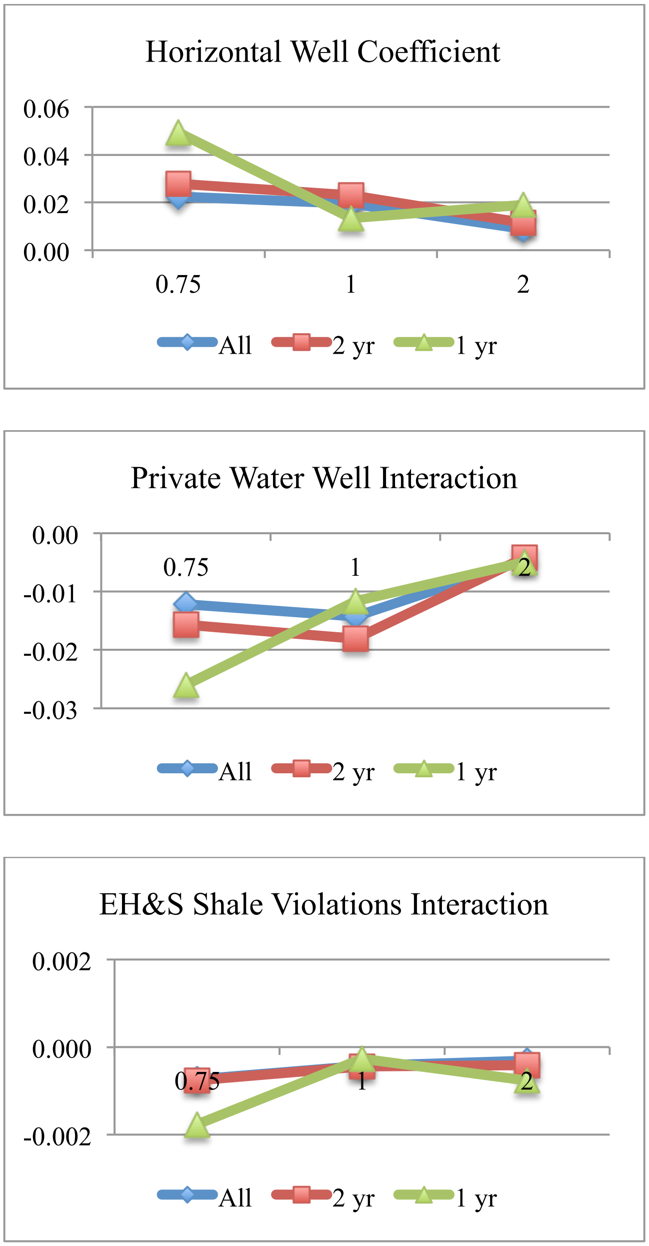
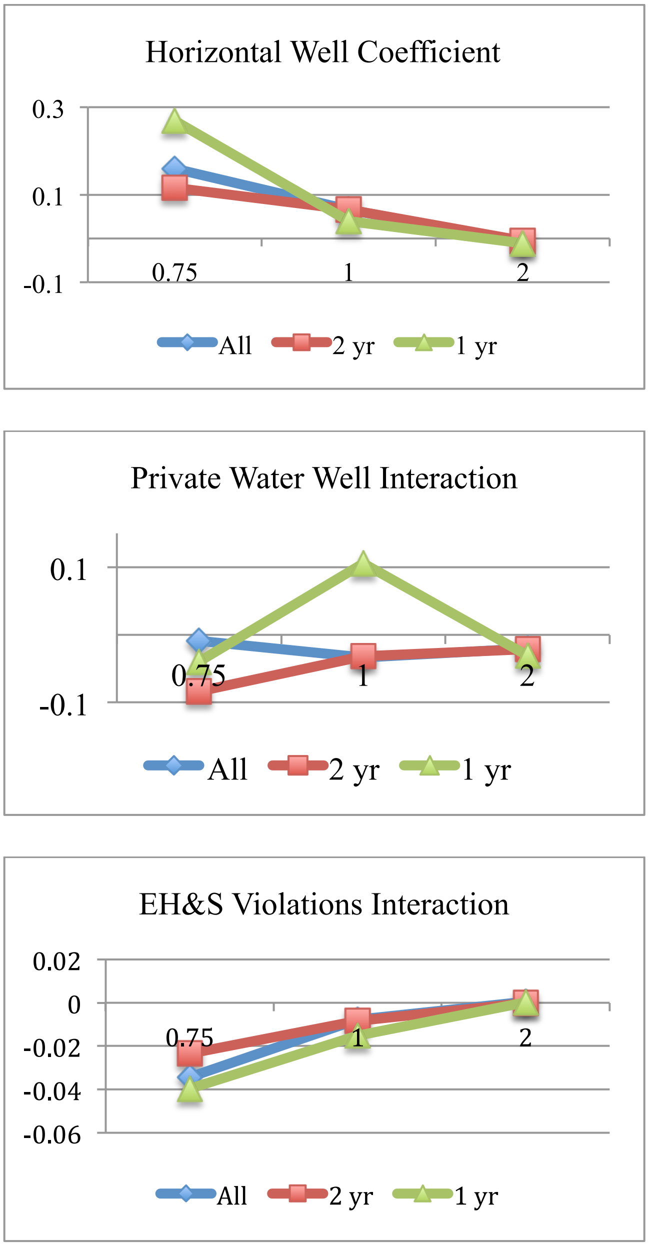


Figure 2. Coefficients of Interest, Westmoreland County.



APPENDIX B

APPENDIX TO CHAPTER II

In this Appendix, I provide additional analysis of anti-fracking actions adopted by towns in New York. Specifically, I include controls for towns with different election systems and provide more analysis of moratoria adoption.

All Bans and Moratoria

There were six towns that passed a ban or a moratorium despite not lying in a county that intersects with the Utica or Marcellus shale formations. These towns are listed in Table 29, but they were not included in any regressions. Finally, there were cities and villages that passed bans or moratoria, but these were also not included in any regressions in order to keep the observational units the same (towns). A list of some of these cities and villages is provided in Table 30.

Ward-Voting Towns

There are thirteen towns in New York that employ the ward system of electing councilpersons instead of an at-large voting system. A ward system divides the population into wards, typically four, and each ward is responsible for electing a councilperson. Hence, in a ward system, each councilperson would be motivated by the median voter from the specific ward that is responsible for his election and not necessarily by the median voter of the town as a whole. Six of the thirteen ward-voting towns are relevant for this study as they lie in a county that intersects with the Utica or Marcellus shale. These towns are Camillus (Onondaga), Ellicott (Chautauqua), Greece (Monroe), New Hartford (Oneida), Salina (Onondaga), and Wallkill (Orange). I constructed a binary variable that denotes whether the town is one of these six ward-voting towns. Table 31 presents the main results after controlling for these towns. Ward-voting towns are associated with about a three percent higher probability of adopting a ban on fracking. The qualitative results for other variables remain the same.

Moratoria Results by Duration

To account for moratoria variability, I divide moratoria towns into groups based on the adopted duration of the moratorium. Specifically, I separate those towns that adopted a moratorium lasting at least one year (long moratoria, 97 towns), and those towns that adopted a moratorium lasting less than one year (short moratoria, 26 towns). These results are summarized in Table 32. Specifically, the results for towns that adopted a long moratorium are similar to the results for towns adopting any moratoria, summarized in Table 13. The results for towns that adopted a short moratorium, however, are more similar to the results for towns adopting bans, summarized in Table 11. This finding may seem surprising, but the data show that a short moratorium is more likely to lead to the adoption of a ban. The correlation between moratoria duration and eventual ban adoption is -0.27, and in a regression, the coefficient on moratoria duration is negative and statistically significant, as summarized in Table 33. It is possible that towns expecting to adopt a ban (perhaps only needing time to draft legislation for a ban) purposefully enact shorter moratoria. Alternatively, the need to frequently renew the moratorium might increase visibility of the issue in the town, facilitating the accumulation of sufficient support for a ban.

Comprehensive Analysis of Adoption of Bans and Moratoria

In this section, I focus on the different ways that towns could adopt a ban or a moratorium or both. Table 34 provides a roadmap for the following tables. Basically, in Table 35, I analyze the probability of adopting a ban conditional on having a moratorium, summarized in equation 1, and the probability of adopting a ban conditional on not having a moratorium, summarized in equation 2. And in Table 36, I analyze the probability of a moratorium that is eventually converted into a ban, summarized in equation 1, the probability of a moratorium that does not lead to a ban, summarized in equation 2, and the probability of adopting a moratorium after excluding towns that adopted a ban.

Overall, some patterns emerge. Of towns with moratoria, those with high water risks are most likely to covert the moratoria into permanent bans on fracking. The coefficients on the county proportion relying on private well water and on the daily county water withdrawals for livestock are positive, large in magnitude, and statistically significant. Meanwhile, the results for ban adoption for towns without moratoria are similar to the results for ban adoption for all towns, except that the coefficients are much smaller in magnitude. The results for moratoria that lead to bans are also similar to the results for all bans, previously summarized in Table 11, while the results for moratoria that do not lead to bans are similar to the results for all moratoria, summarized in Table 13. These results suggest that towns with the greatest water risks, a low proportion of active Republicans, a high percent of owner-occupied homes, and little experience with drilling were most likely to adopt short moratoria on fracking and then replace those moratoria with permanent bans. Towns with lower water risks but with a high proportion of active Democrats and little experience with drilling were most likely to adopt long moratoria that may have been largely symbolic gestures.

Table 29. Off-Shale Town Bans and Moratoria.

Bans	Moratoria
Red Hook Livingston	Copake Germantown Oppenheim Taghkanic

Notes. Both bans were adopted in 2013, and all of the moratoria were adopted in 2012. These actions were not analyzed in this study.

Table 30. Non-Town Bans or Moratoria.

Cities	Villages
Albany	Altamont
Auburn	Clinton
Beacon	Dolgeville
Binghamton	Hudson
Buffalo	Owego
Canandaigua	Oxford
Little Falls	Penn Yan
New York City	Sharon Springs
Niagara Falls	Trumansburg
Olean	Whitesboro
Oneonta	Wilson
Rochester	
Rome	
Saugerties	
St. Johnsville	
Syracuse	
Utica	

Notes. This list is not an exclusive list of cities and villages that adopted bans or moratoria on fracking.

Table 31. Controls for Ward-Voting Towns, Cross-Sectional Probit.

Variables	Ban (1)	Moratorium (2)
Ward System	0.033**	-0.068
	(0.016)	(0.081)
Water Variables		
Proportion Relying on Private Well Water, by county	0.014**	-0.254***
	(0.006)	(0.094)
Livestock Private Withdrawals, by county	0.007***	0.092***
	(0.002)	(0.027)
Crop Irrigation Private Withdrawals, by county	-0.001	-0.027
	(0.002)	(0.042)
Domestic Water Wells/1,000	0.014*	-0.064
	(0.007)	(0.170)
Agriculture or Irrigation Wells/1,000	0.185**	-40.553*
	(0.077)	(20.962)
Drilling Variables		
Vertical Well Development/1,000	-0.064**	-0.720***
	(0.028)	(0.269)
Horizontal Well Development/1,000	-2.626***	-7.075
	(0.906)	(4.354)
Political Variables		
Prop. Active Democrats, by county	0.043**	-0.467
	(0.019)	(0.410)
Prop. Active Republicans, by county	-0.121***	-0.704*
	(0.024)	(0.393)
Prop. Active Greens or Independents, by county	-0.453**	-2.201
	(0.229)	(3.842)
Recycling Variable		
Recycling Rate, by county	0.037***	0.616***
	(0.012)	(0.160)
Demographic Variables		
Logarithm of Median Income	-0.010**	-0.052
	(0.005)	(0.091)
Logarithm of Town Population	-0.002**	-0.003
	(0.001)	(0.015)
% Age 25+ w/ High School Degree/1,000	-0.349**	-11.496***
	(0.174)	(3.641)
% Age 25 w/ More than a High School Degree/1,000	0.290**	-3.601
	(0.134)	(2.902)

Variables	Ban (1)	Moratorium (2)
% Unemployed/1,000	-0.022	-3.418
	(0.218)	(4.086)
% Under 19 Years Old/1,000	-0.352***	-4.392
	(0.132)	(2.730)
% Black/1,000	0.275*	-7.005*
	(0.147)	(4.070)
% Owner-Occupied Homes/1,000	0.206***	1.187
	(0.079)	(1.618)
Observations	688	688

Table 32. Moratoria by Adopted Duration, Cross-Sectional Probit.

Variables	Long, 12+ months (N=97) (1)	Short, <12 months (N=26) (2)
Water Variables		
Proportion Relying on Private Well Water, by county	-0.204*** (0.075)	-2.7e-4 (0.009)
Livestock Private Withdrawals, by county	0.039* (0.021)	0.013*** (0.003)
Crop Irrigation Private Withdrawals, by county	-0.024 (0.033)	-0.003 (0.004)
Domestic Water Wells/1,000	-0.169 (0.127)	0.016 (0.016)
Agriculture or Irrigation Wells/1,000	-18.402 (14.890)	-5.172** (2.575)
Drilling Variables		
Vertical Well Development/1,000	-0.842*** (0.251)	-0.019 (0.022)
Horizontal Well Development/1,000	-3.171 (3.264)	-0.838 (1.003)
Political Variables		
Prop. Active Democrats, by county	-0.913*** (0.332)	0.108*** (0.032)
Prop. Active Republicans, by county	-0.601* (0.313)	-0.023 (0.034)
Prop. Active Greens or Independents, by county	-1.195 (3.093)	-0.199 (0.430)
Recycling Variable		
Recycling Rate, by county	0.360*** (0.123)	0.044*** (0.017)
Demographic Variables		
Logarithm of Median Income	0.031 (0.072)	-0.023*** (0.009)
Logarithm of Town Population	0.002 (0.012)	-0.001 (0.001)
% Age 25+ w/ High School Degree/1,000	-6.747** (2.904)	-0.843** (0.332)
% Age 25+ w/ Bachelor's Degree/1,000	-3.746 (2.386)	0.183 (0.253)
% Unemployed/1,000	-3.419 (3.340)	0.045 (0.350)

Variables	Long, 12+ months (N=97) (1)	Short, <12 months (N=26) (2)
% Under 19 Years Old/1,000	-2.238	-0.319
	(2.258)	(0.237)
% Black/1,000	-5.123	-0.191
	(3.300)	(0.352)
% Owner-Occupied Homes/1,000	-0.466	0.463***
	(1.314)	(0.176)
Observations	688	688

Notes. Robust standard errors in parentheses. Coefficients have been transformed to reflect the marginal effects on the probability of a moratorium. *** p<0.01, ** p<0.05, * p<0.1.

Table 33. Bans by Adopted Duration of Moratoria, Cross-Sectional Probit.

Variables	Ban
Moratoria Duration	-0.051***
	(0.014)
Observations	119

Notes. Robust standard errors in parentheses. The coefficient has been transformed to reflect the marginal effects on the probability of adopting a ban. The sample includes all towns that adopted moratoria. *** p<0.01, ** p<0.05, * p<0.1. For towns with moratoria, the correlation between moratoria duration and the adoption of a later ban is -0.27.

Table 34. Comprehensive Analysis of Bans and Moratoria Summary.

	All	Shale	Estimated Probability	N	Table
Ban	58	56	Pr(Ban=1)	688	Table 11
Nothing → Moratorium → Ban	27	27	Pr(Ban=1 | Mora = 1)	119	Table 35
Nothing → Ban	31	29	Pr(Ban=1 | Mora = 0)	569	Table 35
Moratorium	123	119	Pr(Mora=1)	688	Table 13
Nothing → Moratorium → Ban	27	27	Pr(Mora=1 & Ban=1)	688	Table 36
Nothing → Moratorium (no Ban)	96	92	Pr(Mora=1 & Ban=0)	688	Table 36
Nothing → Moratorium (sample excludes Bans)	96	92	Pr(Mora=1) & sample excludes Ban towns	632	Table 36

Table 35. Conditional Probability of Adopting a Ban, Cross-Sectional Probit.

Variables	Pr(Ban=1 | Moratorium=1) (1)	Pr(Ban=1 | Moratorium=0) (2)
Water Variables		
Proportion Relying on Private Well Water, by county	0.636***	2.3e-5**
	(0.244)	(8.9e-6)
Livestock Private Withdrawals, by county	0.234**	7.5e-6**
	(0.096)	(3.0e-6)
Crop Irrigation Private Withdrawals, by county	0.195	-3.0e-6
	(0.129)	(2.7e-6)
Domestic Water Wells/1,000	-0.470	1.8e-5*
	(0.547)	(9.4e-6)
Agriculture or Irrigation Wells/1,000	-120.892*	3.6e-4*
	(67.086)	(2.0e-4)
Drilling Variables		
Vertical Well Development/1,000	-2.010**	-2.5e-4
	(0.955)	(1.6e-4)
Horizontal Well Development/1,000	-129.840*	-1.5e-4
	(74.080)	(0.001)
Political Variables		
Prop. Active Democrats, by county	2.520*	3.8e-5
	(1.496)	(2.5e-5)
Prop. Active Republicans, by county	-3.327**	-1.3e-4***
	(1.461)	(3.4e-5)
Prop. Active Greens or Independents, by county	-36.167***	-4.2e-4
	(9.976)	(3.8e-4)
Recycling Variable		
Recycling Rate, by county	0.916*	3.8e-5**
	(0.491)	(1.6e-5)
Demographic Variables		
Logarithm of Median Income	-0.266	-1.0e-5*
	(0.277)	(5.4e-6)
Logarithm of Town Population	0.007	-2.0e-6*
	(0.040)	(1.2e-6)
% Age 25+ w/ High School Degree/1,000	-5.170	-2.8e-4
	(6.982)	(2.2e-4)
% Age 25+ w/ Bachelor’s Degree/1,000	4.542	4.2e-4**
	(4.636)	(1.7e-4)
% Unemployed/1,000	4.084	-3.1e-5
	(10.299)	(2.4e-4)

Variables	Pr(Ban=1 | Moratorium=1) (1)	Pr(Ban=1 | Moratorium=0) (2)
% Under 19 Years Old/1,000	-21.069***	-1.7e-4
	(5.805)	(1.7e-4)
% Black/1,000	5.429	4.2e-4**
	(4.678)	(1.9e-4)
% Owner-Occupied Homes/1,000	0.946	2.0e-4*
	(3.245)	(1.2e-4)
Observations	119	569

Notes. Robust standard errors in parentheses. Coefficients have been transformed to reflect the marginal effects on the probability of a ban. *** p<0.01, ** p<0.05, * p<0.1.

Table 36. Probability of Adopting a Moratorium, by Ban Adoption, Cross-Sectional Probit.

Variables	Pr(Moratorium=1 & Ban=1) (1)	Pr(Moratorium=1 & Ban=0) (2)	(Moratorium=1), excluding Bans (3)
Water Variables			
Proportion Relying on Private Well Water, by county	0.002	-0.274***	-0.253***
	(0.004)	(0.086)	(0.089)
Livestock Private Withdrawals, by county	0.004***	0.060**	0.069***
	(0.001)	(0.024)	(0.024)
Crop Irrigation Private Withdrawals, by county	6.0e-5	-0.044	-0.030
	(0.002)	(0.039)	(0.041)
Domestic Water Wells/1,000	0.002	-0.099	-0.089
	(0.007)	(0.158)	(0.163)
Agriculture or Irrigation Wells/1,000	-2.421**	-16.528	-17.249
	(1.116)	(16.123)	(17.040)
Drilling Variables			
Vertical Well Development/1,000	-0.036*	-0.473**	-0.577**
	(0.021)	(0.231)	(0.246)
Horizontal Well Development/1,000	-1.191*	-4.771	-5.722
	(0.709)	(3.681)	(3.676)
Political Variables			
Prop. Active Democrats, by county	0.036**	-0.782**	-0.708*
	(0.015)	(0.397)	(0.382)
Prop. Active Republicans, by county	-0.045***	-0.266	-0.659*
	(0.016)	(0.360)	(0.373)
Prop. Active Greens or Independents, by county	-0.460**	0.336	-0.332
	(0.210)	(3.427)	(3.446)
Recycling Variable			
Recycling Rate, by county	0.025**	0.403***	0.565***
	(0.011)	(0.136)	(0.160)
Demographic Variables			
Logarithm of Median Income	-0.003	-0.025	-0.061
	(0.004)	(0.082)	(0.083)
Logarithm of Town Population	-2.6e-4	-0.002	-0.007
	(0.001)	(0.014)	(0.014)

Variables	Pr(Moratorium=1 & Ban=1) (1)	Pr(Moratorium=1 & Ban=0) (2)	(Moratorium=1), excluding Bans (3)
% Age 25+ w/ High School Degree/1,000	-0.306*	-7.388**	-8.383**
	(0.167)	(3.193)	(3.331)
% Age 25+ w/ Bachelor's Degree/1,000	0.038	-2.998	-2.031
	(0.132)	(2.609)	(2.641)
% Unemployed/1,000	0.141	-4.752	-5.762
	(0.189)	(3.573)	(3.633)
% Under 19 Years Old/1,000	-0.359***	-0.556	-1.278
	(0.127)	(2.374)	(2.422)
% Black/1,000	0.063	-9.585**	-10.210***
	(0.146)	(3.791)	(3.961)
% Owner-Occupied Homes/1,000	0.164**	-0.282	-0.172
	(0.075)	(1.504)	(1.474)
Observations	688	688	632

Notes. Robust standard errors in parentheses. Coefficients have been transformed to reflect the marginal effects on the probability of a moratorium. *** p<0.01, ** p<0.05, * p<0.1.

APPENDIX C

APPENDIX TO CHAPTER III

In this Appendix, I provide details about the risks to water from drilling contaminants that may be released during various stages of shale development. Ordinary risks of drilling include contamination from blowouts, improper waste disposal, and inadequately sealed abandoned wells, the cumulative environmental effects of which could be significant. Shale drilling techniques also come with uncertain risks of groundwater and surface water contamination from fracking fluid, fracking wastewater, or methane gas that could pass through underground fracture pathways into drinking-water aquifers or that could get spilled on the surface and seep into the water supply. Below, I briefly describe the possible contaminants and explain the pathways for soil and water exposure.[115]

Contaminants

Nearby water or soil can become contaminated when fracking fluid, wastewater, or methane gas migrates through fractures, seeps through improperly cased wells, or spills on the surface during drilling activities, to name a few pathways. By far the most feared contamination is drinking water contamination by fracking fluid or by flowback wastewater (the fracking fluid that returns to the surface when drilling pressure is

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[115] Wiseman (2013) provides a thorough description of risks that arise at different stages of the drilling process.

released).[116] Fracking fluid itself is made up of mostly water (at least ninety-eight percent), sand for propping open fractures, and chemical additives for reducing friction and other purposes (U.S. Department of Energy 2009). Although the overall concentration of chemical additives in most fracking fluids is between a half and two percent, these chemicals have been at the center of much of the fracking controversy because they may present a risk to populations.

A 2011 report by the U.S. House of Representatives Committee on Energy and Commerce found that some commonly used chemical additives were hazardous pollutants or known or possible human carcinogens (U.S. House of Representatives 2011). Exposure to these chemicals could lead to a host of adverse health outcomes, from eye irritations to cancers (Colborn et al. 2011). In fact, a sizeable spill of fracking fluid might trigger emergency response action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), even though the purposeful injection of fracking fluids for well stimulation is not federally regulated.[117] There are also no federal fracking-fluid disclosure requirements for oil and gas operators, and state disclosure requirements vary (Richardson et al. 2013). These inconsistencies mean that some state regulators do not know the kinds of hazards that these wastes may contain. To combat public fear that stems from the uncertainty surrounding the chemical additives, however, some operators have voluntarily disclosed the chemicals used in their fracking

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[116] Fracking wastewater often also contains traces of materials from the shale formation itself, such as salt, oil and grease, and naturally occurring radioactive material (Hammer and VanBriesen 2012).

[117] In the 2005 Energy Policy Act, Congress amended the definition of "underground injection" under the Safe Drinking Water Act to exclude the injection of fracking fluid in the fracking operation itself, unless the fracking fluid contains diesel. 42 U.S.C. § 300h. Hence, generally speaking, no federal permit is required for fracking activities. Some refer to this exception as the "Halliburton loophole," as it was promoted by then Vice President Cheney, who was a former Halliburton Chief Executive Officer (Burger 2013).

operations on an online database called FracFocus.[118] Other companies are trying to eliminate toxic chemicals from fracking fluid and even make fracking fluid environmentally friendly.[119] Of course, as fracking fluid becomes less toxic, fracking-fluid contamination will also become less of a concern.

Water can also become contaminated with methane gas, which is volatile and in high concentrations can increase the risk of explosions. In the anti-fracking documentary *Gasland*, for example, a man is shown lighting his faucet water on fire with great theatrical flare. But, methane in drinking water is not just anti-fracking propaganda. High methane concentrations have been identified in private water wells in a few Pennsylvania counties, and residents suspect that drilling activities on the Marcellus shale are to blame. For example, in 2010, Cabot Oil & Gas Corp. settled for $4.1 million with residents of Dimock, Pennsylvania over gas found in their water after state environmental regulators determined Cabot contaminated the aquifer underneath their homes with methane.[120] Operators, meanwhile, contend that methane concentrations either preexist drilling operations or stem from gas leaks within the home. Scientific studies to date are mixed. One recent scientific study found that drilling activities are the likely sources of much nearby methane contamination in Pennsylvania (Osborn et al. 2011), but another Pennsylvania study that tested water wells before and after drilling found that much contamination preexisted drilling activities, at least in the short run (Boyer et al. 2011). Natural gas and petroleum are exempt from the definition of "hazardous waste" under

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[118] FracFocus, http://www.fracfocusdata.org.

[119] Steve Hargreaves. 2011. "Clean Fracking: Moving to Replace Chemicals." *CNN Money*, November 16; Joe Carroll. 2012. "Chesapeake Testing 'Green' Fracking Fluids in Shale Wells." *Bloomberg News*, October 2.

[120] Mary Esch. 2012. "Nationwide Insurance: Fracking Damage Won't Be Covered." *Huffington Post*, July 12.

CERCLA, which suggests that any contamination by methane would not be subject to remedial action under CERCLA.

Contamination Pathways

There are five pathways by which water could become contaminated during shale development: (1) drilling- and fracking-related pathways; (2) blowouts; (3) surface spills or leaks; (4) wastewater disposal; and (5) abandoned wells. Aside from contamination that stems from the fracturing process, the other risk pathways are shared by conventional drilling activities. Shale development, however, adds fracking fluid as a potential contaminant and results in a scaling up of all risks due to the scope and scale of development. The expected magnitudes of harms are uncertain, but likely vary with characteristics of the shale formation, the size of the nearby population, and the population's vulnerability to water contamination.

Drilling- and Fracking-Related Pathways

There are at least three theoretically possible ways that fracking fluid or methane gas could migrate into groundwater sources through the fracturing process (Osborn et al. 2011). First, the fluid and gas could, over time, move from the formation and into drinking-water aquifers. But because thousands of feet of highly pressurized rock separate methane gas and fracking fluid from water sources, drilling-induced natural migration is unlikely. Most scientists agree that this first pathway is further implausible given the short time horizons for fluid and gas movement involved in current cases of alleged contamination.[121] If anything, this risk pathway could result in water contamination that may manifest years later.

Second, fracking could create new fractures or enlarge existing fractures that could then connect to a system of fractures that eventually lead to drinking-water aquifers. Most scientific evidence suggests that single fractures are too short and end at each new rock layer, making it unlikely that they would reach drinking-water aquifers (Davies et al. 2012). But recent scientific evidence suggests that there are significant natural fracture pathways in Pennsylvania that connect deep shale formations to shallow drinking-water aquifers, and fracking activities could increase connections to these fracture pathways and exacerbate the risk of water contamination by methane gas (N. R. Warner et al. 2012). Hence, the likelihood of this risk pathway is disputed, but it would depend on the geology of the particular shale formation and its surrounding area.

Third, improperly cemented or cased wells could be a source of methane contamination of aquifers. Osborn et al. (2011) argue that faulty cement seals around wellbore portions that pass through aquifers, or pass through fracture systems that connect to aquifers, are the likely causes of contamination that they identified in Pennsylvania counties. Considine et al.'s (2013) analysis of environmental violations issued to operators on the Pennsylvania Marcellus shale from January 2008 to August 2011 confirms that such leaks attributed to operator error do occur. The authors identified two methane-migration violations in which improper well cementing and casing were found to affect water supplies for thirty-five families, resulting in total fines to operators

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[121] For example, Osborn et al. (2011) state that their results are not consistent with rapid movement of formation materials to the surface. One study, however, argues that fracking could reduce the transport time for fluids and gas to reach the surface from tens of thousands of years to within ten years (Myers 2012).

of about $2.8 million. Large-scale shale development could increase the incidence of such costly operator errors if appropriate safeguards are not in place.

Despite the public attention to possible contamination from fracking activities, there has not been a confirmed case of drinking water contamination by fracking fluid (Massachusetts Institute of Technology 2011). One study by the U.S. Environmental Protection Agency (EPA), however, concluded that groundwater (but not drinking water) contamination in Pavillion, Wyoming was best explained by hydraulic fracturing operations (U.S. EPA 2011). This situation in Wyoming might be somewhat unique as the monitoring and water wells were relatively deep and the shale formation relatively shallow, thus decreasing the usually large distance between the two. The EPA has since dropped its investigation of the contamination at Pavillion, Wyoming.[122] Other communities have also alleged water contamination by fracking fluid, and the EPA is currently investigating their claims.[123]

Blowouts

Uncontrolled pollution releases could also occur during well blowouts. Blowouts are essentially explosions that occur when operators encounter an unanticipated level of pressure when drilling. The explosion could release drilling fluids or methane gas into surface waters or groundwaters, such as what happened in Clark, Wyoming. Blowouts are not uncommon drilling events. Chesapeake Energy, for example, was involved in a

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[122] Mead Gruver and Ben Neary. 2013. "Pavillion, Wyoming Fracking Pollution Study Dropped By EPA, Investigation Turned Over To State." *Huffington Post*, June 20.

[123] U.S. EPA, Case Study Locations for Hydraulic Fracturing Study, http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/case_studies.cfm. The EPA also still plans to release a report on fracking's potential impact on drinking water sources in 2014. U.S. EPA, EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources, http://www2.epa.gov/hfstudy.

few high-profile blowout incidences in 2011 and 2012. In April 2011, a blowout at a Chesapeake Marcellus shale well spilled thousands of gallons of fracking fluid in Bradford County, Pennsylvania.[124] The blowout took six days to control, and the fracking fluid flowed into a nearby creek. In January 2012, the company made headlines when a well near Sweetwater, Oklahoma blew out, and the well did not have a blowout preventer.[125] In addition, an internal review found that the unanticipated pressure zone that led to the blowout was likely caused by a production casing that previously failed in one of the company's nearby wells. And again in April 2012, another Chesapeake well, this time one drilled in the Niobrara Shale near Douglas, Wyoming, suffered a blowout, releasing methane into the atmosphere and leading to the evacuation of more than sixty residents.[126] Although these examples involved the contamination of soil, air, or surface waters, it is possible that an underground blowout could contaminate groundwater.[127]

Surface Storage or Transport

There is also the possibility that water or soil could become contaminated through surface spills from drilling activities, especially the improper storage of fracking wastewater. Fracking wastewater is often stored on site in pits, at least temporarily, and then transported for treatment or for injection into a disposal well. Spills could occur when wastewater is transported between onsite containers or when it is improperly enclosed in a storage container. Considine et al. (2013) identified almost one hundred and

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[124] Edward McAllister. 2011. "Chesapeake Stems Flow from Blown Pennsylvania Gas Well." *Reuters*, April 22.

[125] Paul Monies. 2012. "Chesapeake Pays $75,000 Fine For Problems that Led to Oklahoma Well Blowout." *NewsOK*, July 21.

[126] Selam Gebrekidan and Joshua Schneyer. 2012. "Chesapeake Well Leaks in Wyoming, Residents Evacuate." *Reuters*, April 25.

[127] John Wright Co., Part 6—Underground Blowouts, http://www.jwco.com/technical- litterature/p06.htm.

fifty violations for minor spills (spilling less than four hundred gallons) and nine violations for major spills in Pennsylvania between January 2008 and August 2011. Wiseman (2012) similarly found that surface spills accounted for about twenty-five percent of violations in Michigan and almost forty percent of violations in New Mexico. If spills or leaks are not cleaned up, then contaminants can migrate into groundwater sources. In New Mexico, a state study found that between the mid-1980s and 2003 there were about 7,000 cases of soil and water contamination and 400 cases of groundwater contamination caused by watewater leaked from drilling pits.[128]

In fact, when Resources for the Future surveyed experts in government, industry, universities, and nongovernmental organizations about the risks of shale gas development, surface water contamination through spills emerged as a risk of high concern (Krupnick, Gordon, and Olmstead 2013). Under CERCLA, operators must report qualifying spills of hazardous substances,[129] but states are responsible for ensuring that proper regulations are in place to prevent such spills, and these state regulations vary widely. Some states, for example, have prohibited the use of pits, require secondary containment around storage tanks or pits, or mandate setbacks from sensitive resources, while other states do not have such preventative regulations (Richardson et al. 2013). There are also concerns that some state regulators lack the resources and the knowledge to enforce these specific regulations.[130]

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[128] Laura Paskus. 2012. “New Mexico’s ‘Fracking’ Legacy.” *KUNM*, July 11.

[129] 42 U.S.C. § 9603 (2013).

[130] Gayathri Vaidyanathan. 2013. “Pits for Fracking Waste Often Fall Short of Standards in W.Va.—Report.” *E&E EnergyWire*, March 22. In addition to accidental spills, operators can engage in purposeful illegal dumping of fracking wastewater. For example, Ohio regulators are currently investigating two companies that dumped thousands of gallons of drilling wastewater into a sewer system that linked to a public water system. Ellen M. Gilmer. 2013. “State Revokes Company’s Permits After Wastewater Dumping.” *E&E News*, February 8.

Improper Wastewater Disposal

In addition, risks to water could arise during the disposal of drilling wastewater. Ordinarily, Subtitle C of the Resource Conservation and Recovery Act (RCRA) provides "cradle to grave" management of hazardous wastes.[131] When Congress amended RCRA in 1980, however, it exempted oil and gas wastes pending a study of the wastes by the EPA.[132] In 1988, the EPA concluded that regulating these wastes under RCRA is not necessary in part because "existing [s]tate and [f]ederal regulations are generally adequate to control the management of oil and gas wastes," despite noting that "regulatory gaps do exist" (U.S. EPA 1988). Ultimately, the EPA worried that RCRA regulation would cause an economic crisis because of the importance of energy to the economy. Instead, the management system that now controls fracking wastes combines state regulation with some federal oversight under the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA).

Most operators dispose of drilling wastewater in underground injection wells that are regulated as Class II wells under the SDWA's Underground Injection Control program, requiring a federal permit. Recent violations data show that thousands of disposal wells fail mechanical integrity requirements.[133] When not properly constructed, these wells could become a source of underground pollution.[134] In Midland, Texas, for example, a disposal well leaked wastewater into an aquifer, and the company responsible

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[131] 42 U.S.C. § 6922 (2013).

[132] *Id.* § 8002(m).

[133] Abrahm Lustgarten. 2012. "Injection Wells: The Poison Beneath Us." *ProPublica*, June 21.

[134] Many experts are also concerned about earthquakes caused by disposal wells used for underground injection of fracking wastewater (Frohlich 2012). I do not discuss that risk here because the risk of earthquakes is not commonly considered to be a risk to water. I note, however, that at least some experts believe that earthquakes might be preventable, or at least mitigated, if proper safeguards are taken by those operating drilling and injection activities.

for the maintenance of this well went bankrupt.[135] Injection wells may also cause nearby rock layers to fracture, thereby allowing the wastewater to migrate over time.[136]

The CWA prohibits operators from directly discharging wastewater from shale gas wells to surface waters, but operators could send their wastewater to treatment plants that receive special permits from the EPA.[137] These treatment plants, however, might not be equipped to properly handle and sufficiently treat the wastes.[138] These plants would then release the partially treated water into surface waters when the wastewater could still be hazardous to ecosystems, wildlife, or human health.[139] The Natural Resources Defense Council estimates that in Pennsylvania in 2011 about sixty percent of wastewater went to privately owned water treatment plants and about one percent went to publicly owned wastewater treatment plants (Hammer and VanBriesen 2012). In May 2011, the Pennsylvania agency charged with regulating oil and gas activities requested companies to voluntarily stop sending their drilling wastewater to treatment plants,[140] which improved the quality of the treatment plants' effluent discharges (Ferrar et al. 2013). Other researchers have also found that the treatment and release of drilling wastewater by permitted facilities upstream is associated with poorer quality surface water downstream (Olmstead et al. 2013). As a result, more states, such as New Jersey, are discussing

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[135] Kate Galbraith and Terrence Henry. 2013. "As Fracking Proliferates in Texas, So Do Disposal Wells." *TexasTribune*, March 29.

[136] Abrahm Lustgarten. 2012. "Whiff of Phenol Spells Trouble." *ProPublica*, June 21.

[137] 33 U.S.C. §§ 1251, 1311, 1342 (2013).

[138] This is not just a concern with shale gas drilling, but could be an issue with all oil and gas drilling. Mike Soraghan. 2013. "Drillers Send Conventional Brine to Treatment Plants." *E&E EnergyWire*, March 20.

[139] A Delaware wastewater plant, for example, processed over a million gallons of drilling wastes in 2009 and 2010 and then released the processed wastes into a nearby waterway, raising these fears. "Fracking Wastewater Makes Way to State, Stirring Debate on Regs." 2012. *E&E EnergyWire*, May 22. Ellen M. Gilmer. 2012. "With the Right Permit, Treated Brine Can Head to Ohio Rivers." *E&E EnergyWire*, July 9.

[140] Pennsylvania has since passed regulations that contain permitting standards for these wastewater discharges from treatment plans.

whether to prohibit municipal treatment plants from accepting drilling wastes.[141] The EPA is considering setting standards for fracking wastewater that must be achieved before the wastes could go to a treatment facility, and it hopes to issue a proposed rule in 2014.[142] Going forward, the hope is that most wastewater will be recycled and reused in future drilling activities.

Unplugged Abandoned Wells

Finally, operators may abandon wells without properly plugging the wells (usually by sealing the well with cement) and otherwise ensuring that the well site is restored. This risk arises because operators may not have a financial incentive to engage in these activities after they finish production at the well. More worrisome, however, is that even properly plugged wells can leak and contaminate soil and water over time.

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[141] The New Jersey legislature, for example, voted in June 2012 to ban treatment of fracking wastes within the state, although Governor Christie vetoed the bill. Mireya Navarro. 2012. "New Jersey Senate Bans Treatment of Fracking Waste." *New York Times, Green Blog*, June 25.

[142] U.S. EPA. 2011. "EPA Announces Schedule to Develop Natural Gas Wastewater Standards." October 20. http://yosemite.epa.gov/opa/admpress.nsf/0/91E7FADB4B114C4A8525792F00542001.

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