Policy Monitor

Bonding Requirements for U.S. Natural Gas Producers

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Introduction

Hydraulic fracturing and other recent technological advances have dramatically increased the availability of natural gas in the United States. Moreover, since peaking in 2008, U.S. natural gas prices have fallen dramatically, and industry analysts are forecasting that prices will remain low for the next several decades (e.g., U.S. DOE 2013a). These trends have broad implications for energy markets, the economy, and the environment. Energy is a key input in virtually all sectors of the U.S. economy, and inexpensive natural gas is good for growth. Natural gas is also less carbon-intensive than other fossil fuels, leading some experts to describe the fuel as a possible "blue bridge to a green future" (Rotman 2012).

However, these new forms of natural gas production have also raised a number of environmental concerns, including the potential contamination of groundwater and the increased scope for large-volume surface spills. In response, the U.S. Environmental Protection Agency (EPA) and other organizations are working to better understand the potential risks that hydraulic fracturing and other natural gas production methods pose to human health and the environment, but it will be years before comprehensive analyses are completed.

Although the scope for environmental damages from these new forms of gas production is still poorly understood, it is not too early to examine the underlying *incentives* faced by producers. Natural gas producers are constantly making tradeoffs between money, time, and environmental risk. While the private costs and benefits of drilling are realized immediately, the *external* costs are not. This means that by the time external costs are well understood, producers may no longer exist or may not have sufficient resources to finance necessary cleanups or to compensate those who have been adversely affected. Because producers do not face the total cost of potential external damages, they may take too many risks.

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This article discusses alternative regulatory approaches for mitigating the moral hazard problem in U.S. natural gas production. The discussion draws heavily on the broad literature in law and economics, particularly the economic analysis of accident law. One of the overarching themes of these analyses is the inability of any single regulatory approach to yield the socially desirable level of environmental protection by producers. Direct regulation is imperfect because monitoring is costly; the U.S. tort system requires less monitoring but is limited by bankruptcy protection laws; and although mandatory insurance for producers helps to ensure that funds are available to pay for cleanups, it does not correct the underlying moral hazard problem. This article focuses on bonding requirements as an important additional policy tool. Although bonding (i.e., requiring that producers post bonds that can be used to pay for claims made against the company) has tended to receive less attention from policy makers than other regulatory approaches, it has a long history in the U.S. natural gas market and is quite well suited to addressing many of the environmental risks in this market.

An important caveat is in order. Bonding requirements make sense for addressing risks to groundwater, surface water, land contamination, and on-site reclamation when production has been completed. But bonding is unlikely to be an effective approach for reducing air pollution or greenhouse gas emissions. These are fundamentally very different because the damages cannot be observed *ex post*. That is, once a well has been constructed, it is basically impossible to determine what air pollutants or greenhouse gases have been released. Because bonding requirements, mandatory insurance, and the tort system all require that damages be *observable*, these approaches are poorly suited to addressing the air and greenhouse gas impacts of natural gas production.

The article proceeds as follows. The next section provides background on the environmental risks from natural gas production, particularly from shale gas and other unconventional natural gas sources. This is followed by a discussion of the moral hazard problem and the three main regulatory approaches (the tort system, direct regulation, mandatory insurance) for addressing it. Then I turn to bonding requirements, including discussions of benefits and costs, existing federal and state requirements, and some additional issues in policy design. The final section offers a summary and some concluding comments.

Background

This section describes recent trends in natural gas production, particularly from unconventional sources, and discusses some of the potential environmental risks, including examining how producer decisions affect the probability of accidents.

Trends in Unconventional Natural Gas Production

Natural gas producers have long known that shale and other rock deposits contain large amounts of natural gas, but only recently has it become possible to access these reserves cost-effectively. Hydraulic fracturing has become possible through advances in two technologies. First, improvements in horizontal drilling techniques now allow drillers to control drilling operations thousands of feet below the earth's surface. Second, computer applications can map these underground resources with a high degree of detail.

Unconventional natural gas sources, including shale gas, coal-bed methane, and "tight" gas currently account for almost two-thirds of U.S. natural gas production (U.S. DOE 2013a). In terms of future production, shale gas is probably the most important of these three sources. Virtually nonexistent just a few years ago, shale gas has grown rapidly, representing 34 percent of all U.S. natural gas production in 2011 and is forecast to more than double by 2035 (U.S. DOE 2013a).

This dramatic increase in the supply of natural gas has important implications for U.S. and international energy markets. In fact, since their peak in 2008, U.S. natural gas prices have fallen dramatically. As of August 2014, prices were at less than one-third of their peak level and predicted to remain low for the next two decades (DOE 2013a, 2014a). Figure 1 presents the historical trend in U.S. natural gas prices from 1990 to 2012 and predicted prices through 2035. These low prices mean that natural gas has become the fuel of choice in many sectors of the U.S. economy. For example, most of the growth in U.S. electricity generation capacity over the next three decades is forecast to come from natural gas.[1]

In terms of environmental implications, natural gas is less carbon-intensive than other fossil fuels. For example, per unit of electricity generation, natural gas emits about half the carbon dioxide of coal. The differences are even greater for local and regional pollutants such as sulfur dioxide, nitrogen oxides, and particulates. Muller, Mendelsohn, and Nordhaus (2011) calculate that the external costs of local and regional pollutants from natural-gas–fired electricity generation are about one-thirtieth of those from coal-fired electricity generation.

Potential Environmental Risks

As noted in the Introduction, unconventional natural gas production also raises a number of environmental concerns, especially risks to groundwater and surface water.

Well construction and risks to groundwater

To illustrate how groundwater contamination might occur, it is helpful to first briefly describe the well construction process. Shale gas and other unconventional natural gas resources are accumulations of natural gas that are *trapped* within rock or sand formations with low permeability. In contrast, conventional natural gas fields are large, open reservoirs of natural gas. Whereas conventional natural gas resources can be extracted using vertical wells, shale gas reserves usually require horizontal drilling followed by hydraulic fracturing to open these rock or sand formations and create pathways through which the natural gas can move.

Drilling a well consists of several steps.[2] The producer first drills a shallow well, lines the well with steel pipe (casing), and then cements the pipe by pumping cement between the casing and the wall of the wellbore (i.e., the hole that has just been drilled). This process of drilling, casing, and cementing is repeated several times at progressively lower depths. These first steps are critical from an environmental perspective because groundwater is present only at shallow

[1]Natural gas-fired plants account for 63% of new US electricity generating capacity from 2012 to 2040 in the DOE's baseline forecast (DOE 2013a). At current natural gas prices, the total lifetime cost of electricity from natural gas plants is $67 per megawatt hour, compared to $100 for coal, and even more for renewable forms of electricity generation such as wind and solar (DOE 2013b).

[2]For a general overview of well construction and additional discussion of potential environmental risks see MIT (2011) and Richardson et al. (2013), and the references therein.

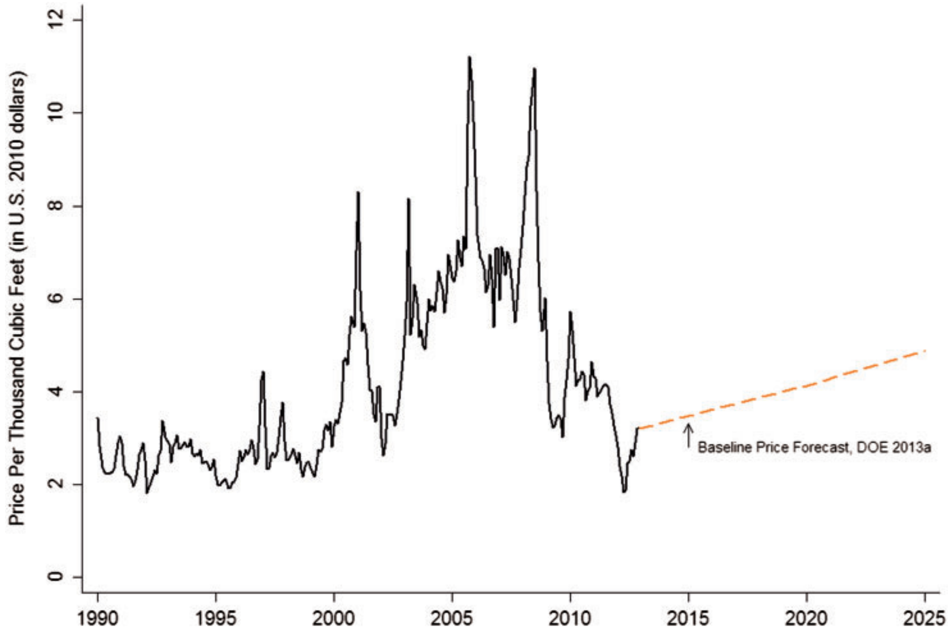

Figure 1 U.S. Natural Gas Prices
Source: Author's tabulation based on data from U.S. Department of Energy (2013a, 2014b).

depths (less than 1,000 feet). Horizontal drilling starts once the target zone (i.e., where the natural gas is located) has been reached. For shale gas, this typically occurs between 5,000 and 10,000 feet (MIT 2011). The producer then injects large quantities of water, sand, and chemicals at high pressure into the horizontal well to break apart the rock and sand formations, thus opening pathways through which the natural gas can flow.

Throughout well construction producers are making decisions that influence the probability of accidents. Casing and cementing have been used for decades, and most producers are experienced in these techniques. However, these steps require time, patience, and effort in order to minimize the risk of failures in the wellbore.[3] The producer also makes important choices after the wellbore is completed. High-pressure and sonic tests are available that allow producers to evaluate the integrity of the wellbore before they begin hydraulic fracturing. For example, if the cement has not adhered adequately to the steel casing, there are techniques for recementing the well. Again, however, proper implementation of these tests takes time, patience, and effort.

Advanced drilling techniques and risks to surface water

Advanced drilling techniques also have the potential to contaminate surface water. As noted earlier, hydraulic fracturing requires the injection of large quantities of chemically treated water into the wellbore. These fracking fluids contain many different chemicals, some of which are toxic and hazardous to human health and the environment (MIT 2011). Much of this water stays in the well or can be reinjected into the well after natural gas has been extracted. But the remaining wastewater must either be treated or stored on-site, raising the potential for surface spills and contamination, and introducing risks that simply do not exist with traditional drilling.

[3]There is some emerging empirical evidence concerning possible links between natural gas drilling and groundwater contamination (see, e.g., Osborn et al. 2011).

Wastewater is typically stored on-site in large surface pits lined with impermeable plastic, and then loaded into tanker trucks. It is essential that these pits be large enough, well constructed, and well maintained, which again requires time, patience, and effort, and precaution must be taken in transferring wastewater in and out of the pits and trucks. Moreover, constructing surface pits and maintaining a fleet of tanker trucks is expensive, so producers are constantly trading off operating cost against the private cost of environmental damages. Mistakes in wastewater handling may impose large environmental costs, particularly if the wastewater reaches a lake, river, or other surface water.[4]

Natural gas drilling also poses the risk of a blowout (i.e., an uncontrolled release of natural gas) because natural gas accumulations are highly pressurized. Blowout preventers and other pressure control equipment are designed to control natural gas as it exits the well, but equipment failure or operator error can lead to an uncontrolled release.[5] Blowouts cause drilling fluids to be spewed over a wide area, causing widespread land contamination and potentially contaminating nearby surface water.[6] Thus, the potential for blowouts is affected by producer decisions and behavior concerning the effective use and maintenance of pressure control equipment.

Policy Approaches for Addressing Moral Hazard

It is clear that prudent behavior by natural gas producers can substantially reduce environmental risks. However, as noted earlier, because of the moral hazard problem, there is generally insufficient incentive for producers to undertake risk-reducing behavior. Thus, the challenge for policymakers is to design regulations that encourage producers to take precautions when constructing and maintaining wells. This section examines three of the main regulatory approaches available for mitigating moral hazard in natural gas production.[7]

The Tort System

One of the most common approaches for addressing environmental damages in the United States is the tort system, whereby anyone who has suffered a loss from a firm's actions can present a claim for compensation in court. The United States has a long history of requiring firms to pay billions of dollars to compensate the victims of environmental damages. Most recently, British Petroleum was forced to pay billions of dollars in damages following the Deepwater Horizon rig explosion in the Gulf of Mexico in April 2010 (Krauss and Schwartz 2012).

[4]Olmstead et al. (2013) perform an econometric analysis of the effect of shale gas development on surface water quality in Pennsylvania, and find evidence of increased pollution downstream from production locations.
[5]This also happens occasionally with oil drilling, as in the recent case of the British Petroleum Deepwater Horizon accident in the Gulf of Mexico.
[6]For example, in April 2011, there was a blowout in a natural gas well in northern Pennsylvania owned by Chesapeake Energy Corp. According to media reports, the well spewed drilling fluids and brine for more than twelve hours, leaking into the Susquehanna River, which flows into Chesapeake Bay (Associated Press 2012). The extent of environmental damages is still not well understood, but the accident underscores the potential for blowouts to cause land and water contamination over a wide geographic area.
[7]Much of the discussion in this section is drawn from the broader law and economics literature. See Shavell (2004) for an overview.

In theory, the tort system could lead firms to internalize potential environmental damages. The ideas are that if firms face the risk of *ex post* penalties when damages occur, they will make *ex ante* choices in order to reduce the risk of damages. Brown (1973) describes the conditions under which strict liability leads agents to take *optimal* levels of precaution. In particular, if there is perfect information and the tort system works perfectly, then agents will internalize all the costs of their actions and thus make choices that minimize expected total social costs.

Limitations of the tort system

In practice, however, the tort system has several important limitations that cause it to fall short of this theoretical ideal (Shavell 1984a, 1984b, 1986). First, firms will only internalize potential future damages if they believe they will indeed be sued for any harm they cause. If there is a probability that they will not be sued, then the incentives for risk-reducing behavior are diluted. For example, high administrative and legal costs mean that not everyone who suffers damages will decide to sue. Moreover, if it is difficult to *attribute* damages to a particular firm, then the probability of legal action is also reduced.[8]

Another limitation of the tort system is that firms are not around forever. As noted earlier, it may take many years for the environmental damages from natural gas production to be realized, and by this time, the producers may no longer exist or have the resources necessary to finance cleanups or to compensate those who have been affected. This insolvency is known in the law and economics literature as the "judgment proof" problem (Shavell 1986), and it undermines the ability of the tort system to bring about the socially desirable level of risk-avoidance.

U.S. bankruptcy laws further insulate firms from potential damages. If potential damages exceed the total value of the company, then victims of damages either will not sue because they know the company cannot afford to pay damages, or will sue, but end up receiving less than their total damages. In both cases, bankruptcy laws serve to insulate firms from the full social cost of their actions; thus, the tort system provides an insufficient deterrent against risky behavior.[9] This is a realistic scenario for natural gas producers, both because the potential damages are large and because much of the drilling is performed by small and medium-sized companies. Thus, as with the limitations of the tort system, bankruptcy protection leads producers to choose higher risk practices than they would if they were responsible for the full costs of all potential environmental damages.

Role of market structure in tort system effectiveness

When accidents occur, large companies are likely to have the resources to pay for environmental damages, but small companies are not. It is important to take this market structure into account when evaluating the potential effectiveness of the tort system. Figure 2 describes market concentration in hydraulic fracturing and, for comparison purposes, in deepwater oil drilling in

[8]There is a substantial law and economics literature that examines the distinction between negligence and strict liability. Under a negligence rule, a firm would be liable only if it had failed to achieve some standard for precaution. Strict liability is broader, holding a firm liable for damages regardless of whether or not it was negligent. See Shavell (2004), pages 224–29, for a discussion of potential challenges in determining negligence.
[9]Pitchford (1995) shows that this is true even when a firm's creditors are also liable for environmental damages.

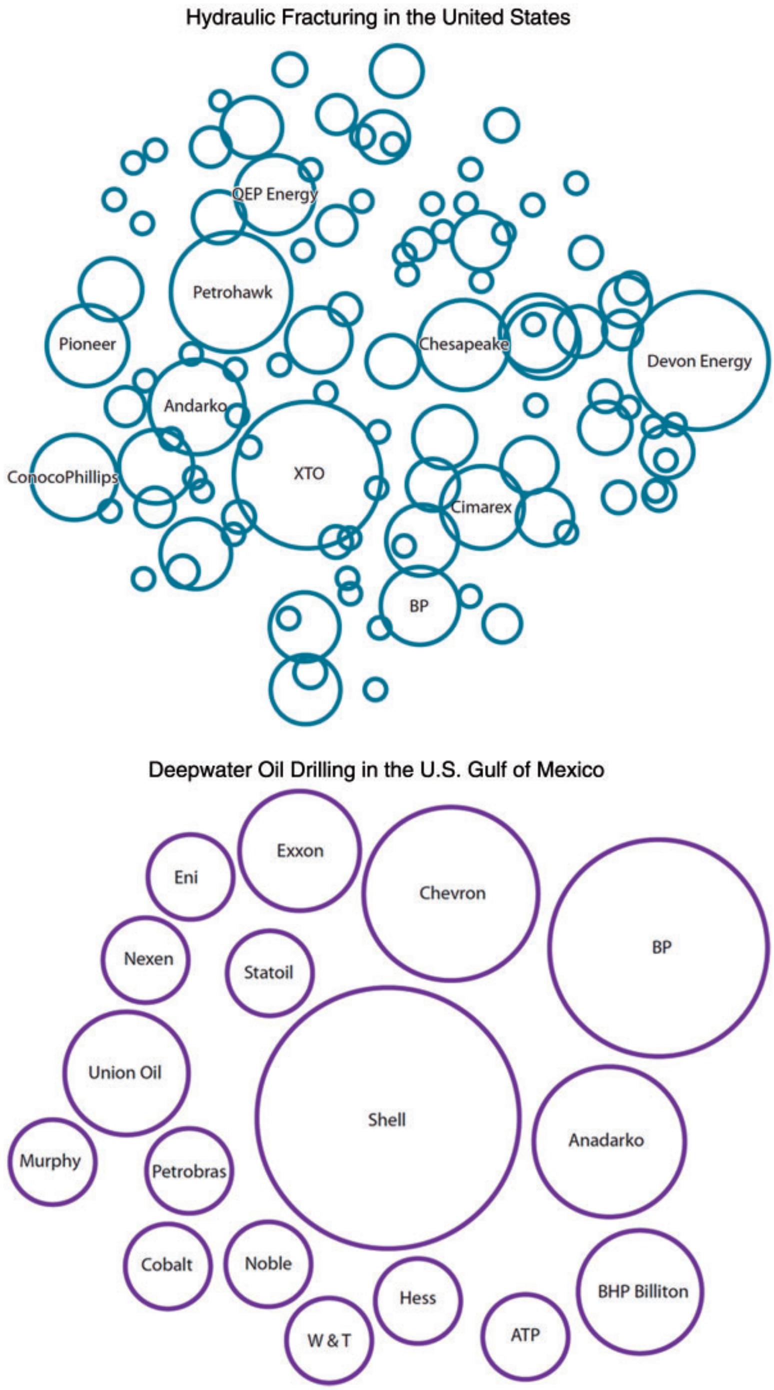

Figure 2 Market Concentration

Notes: See Kellogg (2011) for a discussion of the *SmithBits* data. To focus on hydraulic fracturing, the sample was restricted to all horizontal and directional development wells for natural gas with a target depth in excess of 5000 feet. This resulted in a data set of 442 total wells being produced by 104 producers. The area of the circles is proportional to the number of wells being drilled.

Sources: Constructed by the author using data on active drilling operations from *SmithBits* "U.S. Weekly Rig Detail Report" for March 23, 2012, and *Bureau of Ocean Energy Management, Regulation and Enforcement*, "Current Deepwater Activity" for April 2, 2012.

the Gulf of Mexico. Each circle represents a company actively drilling wells as of Spring 2012, and the area of the circles is proportional to the number of wells drilled.

Figure 2 clearly shows that the hydraulic fracturing market in the United States is relatively unconcentrated, with a large number of companies, but only a few large producers.[10] The largest producer, XTO Energy Inc., has 9 percent of the market and the ten largest producers together account for only 41 percent of the market.[11] In contrast, deepwater oil drilling is more concentrated. As of March 2012, Shell, the largest producer in the Gulf of Mexico, had 24 percent of the market, and the ten largest producers had 78 percent of the market. This market is concentrated because deepwater oil drilling is capital and technology intensive, and only a small number of producers worldwide have the resources and the level of technological sophistication necessary for these projects.

The presence of so many small and medium-sized firms in hydraulic fracturing raises serious concerns about the ability of firms to finance environmental cleanups. Immediately following the Deepwater Horizon accident, British Petroleum established a $20 billion fund to pay for the cleanup and to compensate affected individuals or groups (Weisman and Chazan 2012). Most companies performing hydraulic fracturing do not have this level of financial resources. For most of these producers, a single serious accident would put them into bankruptcy, leaving the cleanup to be financed with public funds.

Direct Regulation

Another approach for addressing environmental damages in the United States is the use of technology requirements and other forms of direct regulation. U.S. natural gas producers are subject to a wide range of direct regulations regarding, for example, site selection and preparation, well spacing, casing and cementing depth, and wastewater storage and disposal.

Advantages of direct regulation

Direct regulation has several advantages over tort liability. In particular, bankruptcy protection is much less of an issue because direct regulation restricts the set of *ex ante* choices available to producers rather than attempting to collect damages *ex post*. Given the market structure in natural gas production, this is potentially an important advantage of direct regulation. Shavell (1984b) also points out that *employee* liability may be different from firm liability. Because an individual employee's personal liability is typically much smaller than the firm's liability, regardless of the size of the firm's assets, employees may not take an appropriate level of risk reduction. In these cases, the tort system alone will be insufficient to eliminate the moral hazard problem, and direct regulation may offer a more effective alternative.

Limitations of direct regulation

One important limitation of direct regulation is that it can be difficult to *enforce*. Natural gas production is geographically dispersed at thousands of sites in more than a dozen states.

[10] In related research, Ringleb and Wiggins (1990) examined small-firm entry into the US economy between 1967 and 1980 and found that small firms were more likely to enter sectors that have more potential liability.
[11] Economists often use the Herfindahl Index (HHI) as a measure of market concentration. The HHI among these natural gas producers is 0.029, vs. 0.106 for deepwater oil drillers in the Gulf of Mexico (author's calculations).

It would be prohibitively expensive to have regulators at all locations.[12] In addition, advanced drilling techniques are highly technical, which means expert regulators are required. Moreover, continued rapid technological innovation in the industry means that regulators need frequent training to keep up with new developments. It is also worth pointing out that regulating agencies draw their employees from the same labor market as oil and gas producers. Even undergraduates with a background in petroleum engineering are earning large salaries (Carnevale et al. 2011), so hiring well-trained regulators is expensive.

A related question is who best understands the potential risks—the producer or the regulator. Shavell (1984b) argues that a key determinant of the relative desirability of tort liability and direct regulation is the possibility of a "difference in knowledge about risky activities." Firms often better understand the costs and benefits of different choices, and in these cases tort liability has an advantage. In contrast, when the regulator knows more than the firm, direct regulation makes more sense. In the case of natural gas production, there is local, site-specific information that is better understood by the producer than the regulator. Every drilling site has unique challenges and issues, and it is thus simply not possible for regulators to anticipate all potential environmental risks.

Direct regulation can also be expensive for producers. Imposing one-size-fits-all requirements for well construction could increase producer's costs unnecessarily. For example, one could require that high-pressure and sonic tests always be used after well construction. Although these risk-mitigation techniques are an important part of the producers' toolkit and can substantially reduce the risk of groundwater contamination, they would also be expensive to implement universally, in terms of both capital and personnel expenditures.

In some cases, direct regulation is the only feasible regulatory approach. As mentioned in the introduction, air pollution and greenhouse gas emissions are fundamentally different from other environmental risks because they cannot be observed *ex post*. This makes it difficult to address these externalities with the tort system, and policy does indeed seem to be heading in the direction of direct regulation. For example, the EPA recently enacted minimum standards that will require natural gas producers to use methane capture equipment by 2015 (EPA 2012).

Mandatory Insurance

Another approach for addressing environmental damages is to require companies to buy insurance that covers the cost of clean-ups when accidents occur. There is a long history of using mandatory insurance in energy markets. In 1989, the Exxon Valdez oil tanker struck a reef off Prince William Sound, Alaska, spilling millions of gallons of crude oil. Following the spill, the *Oil Spill Liability Trust Fund* was established and funded through a tax on domestic and imported oil, currently set at 8 cents per barrel.[13] These funds go into a single communal fund that is available to help pay for damages when accidents occur. Mandatory insurance is also used in the nuclear power industry, with all U.S. nuclear plants required to buy a minimum level of accident insurance in private markets.

[12]Offshore oil drilling faces similar challenges. At the time of the BP Deepwater Horizon oil spill, there were only 60 federal inspectors for 4,000 drilling facilities in the Gulf of Mexico (Calmes and Cooper 2010).
[13]This legislation also set liability caps on oil producers that are not adjusted for inflation. This means the caps have decreased in value over time, thus exacerbating moral hazard (Greenstone 2010).

Insurance helps ensure that funds are available for clean-ups, but it does not address the underlying moral hazard problem because insurance insulates agents from the consequences of their actions. Insurance creates incentives for firms to exercise precaution only if insurers can actually observe risk-reducing behavior (Shavell 1984b). With natural gas production occurring at thousands of different sites, it is difficult and expensive for insurers to monitor producer behavior. This makes it hard to use "risk-adjusted" premiums to encourage safe behavior. For example, ideally insurers would charge different premiums based on the level of effort and expertise with which producers case and cement the wellbore. In practice, however, this level of monitoring is simply infeasible.

Moreover, "experience-rating" is unlikely to meaningfully address moral hazard. In many markets, insurers can observe *ex post* outcomes and then adjust premiums on the basis of prior claims. For example, car insurance premiums are likely to increase after an accident. Although in theory similar adjustments could help reduce moral hazard for natural gas producers, in practice there are a number of important complications. As noted earlier, environmental damages may take many years to be realized, and producers enter and exit the market frequently. Moreover, after a severe accident a producer may simply choose to exit the market rather than pay increased premiums.

Bonding Requirements

There are different types of bonding requirements, but in the simplest example, a producer posts a bond by depositing cash or other liquid assets into a holding account and the bond is not returned until well production has been completed and the producer has complied with all regulatory requirements. This section discusses the benefits and costs of bonding requirements, provides an overview of current federal and state bonding requirements in the United States and discusses some additional issues, including the types of bonds that are available and the use of risk-adjusted minimum bond amounts.

Benefits of Bonding

Bonding requirements help address moral hazard by forcing producers to take potential external damages into account when making choices. Bonding requirements increase the incentive for natural gas producers to act prudently with regard to environmental risks because a producer that avoids environmental damages stands to get back the entire bond. Such actions could include, for example, choosing drilling locations with lower potential environmental damages or exercising additional precaution when casing and cementing a well.

Bonding is most effective when there are a small number of contracting parties, a well-defined time horizon, well-defined definitions of noncompliance, and a high probability of detecting noncompliance (Gerard and Wilson 2009). Natural gas drilling meets these criteria, especially in cases of highly visible damages such as surface spills and blowouts. Because groundwater contamination is less visible and takes longer to detect, it is more difficult to address, not only through bonding requirements, but also through the tort system and mandatory insurance.

Bonding is also effective for ensuring site remediation. When production has been completed, producers are expected to "plug" the well to avoid contamination of groundwater through the wellbore, to remove all equipment, and to restore the land (to the extent possible) to its original condition. Bonding helps ensure compliance with these "end-of-life" requirements, thus avoiding "judgment proof" problems because the producer either no longer exists or does not have the funds necessary to finance remediation.[14]

Costs of Bonding

Bonding also imposes real economic costs. Perhaps most importantly, bonding imposes costs on producers because it ties up operating capital. Typically, producers can post bonds using low-risk assets they have chosen, including certificates of deposit and Treasury securities. This means that the opportunity cost of tying up the producers' operating capital is the *difference* between the rate of return on this low-risk asset and the rate of return the producer would have otherwise received on this capital.

This opportunity cost varies widely across producers depending on their size and access to credit. For a large producer with a substantial cash reserve, the cost is small because the opportunity cost of capital is low. However, many natural gas producers have a cost of capital that is substantially higher than the risk-free rate and for these producers the bonding requirement imposes a cost that is the difference between their cost of capital and the risk-free rate. Moreover, if the bond amount is large enough, it may actually increase the producers' cost of capital. Bonds are liabilities that appear on producers' balance sheets and thus potentially affect their ability to access credit. These costs are highest for small and medium-sized producers and/ or any producer that already has limited access to credit.[15]

Optimal Bond Amounts

The *optimal* bond amount equates the marginal benefit of a higher bond with the marginal cost.[16] But because of the economic costs discussed earlier, optimal bond amounts will necessarily be less than maximum potential damages (Gerard and Wilson, 2009). This is a general result from economic analyses of bonding requirements, but is especially relevant for natural gas producers given the potential, albeit small, for catastrophic damage (e.g., contamination of a large source of drinking water). Although setting the bond amount to the *maximum* potential environmental damage would completely eliminate moral hazard, it would also impose costs on producers that are so high that the total cost would exceed the total benefit.

[14]There are tens of thousands of abandoned oil and gas wells in the United States. According to the GAO (2010), the average cost of reclaiming these sites is about $13,000 per well.
[15]For more on liquidity constraints and the economic costs of bonding requirements, see Shogren, Herriges, and Goviandasamy (1993), Boyd (2001), and Mitchell and Casman (2011).
[16]Determining the optimal bond amount is a challenging exercise that goes beyond the scope of this discussion. In particular, one needs to know not only the entire distribution of potential external damages, but also the *elasticity* of expected damages with regard to the bond amount, both of which are difficult to observe empirically, especially because drilling techniques are evolving rapidly. One also needs to know the producers' cost of capital, the length of the project, and administrative costs. See Gerard (2000) for a conceptual framework and additional details.

Current Federal Requirements

Bonding requirements have played a role in the U.S. natural gas market for more than 90 years. Since passage of the Mineral Leasing Act of 1920, natural gas producers in the United States have been required to post a bond with the U.S. Bureau of Land Management (BLM) prior to drilling on federal lands. These bonds were designed primarily to ensure that producers fulfill their obligations to clean up the drilling site after completion of production, although funds can also be used to pay for environmental clean-ups.

The Mineral Leasing Act and its subsequent revisions established a federal minimum bond amount of $10,000 for an individual lease on federal lands. On average there are about five wells per lease, which implies a minimum bond per well of $2,000. This amount was set in 1960 and has never been adjusted for inflation.[17] Alternatively, producers can post "blanket" bonds, which cover all wells within a given state or nationwide.[18] More specifically, a producer can post a $25,000 bond to cover all of the leases in a given state, or $150,000 to cover all leases in all states (GAO 2010). These amounts for blanket bonds were set in 1951 and have also never been adjusted for inflation.

Since its enactment, this legislation has been aimed at addressing moral hazard. If drilling results in no significant environmental damage and the producer adequately reclaims the drilling site, then the producer receives the bond back in its entirety along with accrued interest. It is only when problems occur that the bond may be used. This is what makes bonds very different from insurance. When a company pays an insurance premium, the money is gone forever, regardless of the producer's subsequent behavior. In contrast, if there is a bond in place, the producer has his own money at stake, and thus has an increased incentive to act prudently.

Federal (and state) laws also require that bonds stay with the wells, not the producers. This means that when a well is sold, the ownership of the bond also transfers, and thus there is no lapse in bond coverage. In cases of bankruptcy, the bonds cannot be used to pay generic company debts until the funds have been returned according to the normal rules for returning bonds—in other words, after a well has finished production. With natural gas wells, production declines quickly after a well is first constructed, but most wells continue to produce at least a small amount of natural gas for many years. When production is completed, the BLM inspects the site and verifies that reclamation efforts have been successful.

Current State Requirements

About one-quarter of hydraulic fracturing occurs on federal land under the jurisdiction of the BLM.[19] The remainder occurs on land under state jurisdiction. State-level requirements extend bonding requirements to drilling on non-federal lands, and in most cases exceed the minimum federal requirements (GAO 2010).[20] Most states have both individual well bonds and blanket bonds, but the size of the bonds varies widely. For example, the minimum dollar amount for individual bonds ranges from $500 (in Kentucky) to $100,000 (in Alaska). In addition, some

[17]This means that the real value of these bonds has eroded substantially. If adjusted for inflation, the minimum bond amount would increase from $10,000 to about $60,000.
[18]Issues surrounding blanket bonds are discussed in more detail later.
[19]Baird Equity Research, quoted in Tennile (2012).
[20]See Appendix table 1 for a list of bonding requirements by state.

states base the minimum bond amount on the depth of the well or other proxies for environmental risk.

Several states have recently increased their bonding requirements, while several others are actively considering changes. For example, in December 2011, West Virginia established a $50,000 bond requirement per well and a $250,000 blanket bond for all of a producer's wells in the state.[21] The South Dakota legislature recently increased bonding requirements to $10,000 for wells drilled below 5,500 feet and $50,000 for wells drilled below 5,500 feet.[22] Maryland recently moved to increase to $50,000 the minimum bond required per well.[23] New York State has a maximum bond amount per deep well of $250,000, the highest maximum bond for any state. In addition to stringent water-use restrictions, this requirement has effectively created a moratorium on hydraulic fracturing (Richardson et al. 2013).

Additional Considerations for Bonding Requirements

There are several additional practical issues that arise with bonding requirements: (i) personal versus surety bonds, (ii) "blanket" bonds, and (iii) risk-adjusted bond amounts.

Personal versus surety bonds

Under current federal legislation, bonds must be one of two types: a personal bond or a surety bond. With a personal bond, the producer deposits the required amount of financial assets in a secured account. Personal bonds typically are required to be low-risk assets such as certificates of deposit or negotiable U.S. Treasury securities. In contrast, a surety bond is a third-party guarantee that the producer purchases from an insurance company. If there are no environmental damages, then the insurance company pays nothing. Surety bonds are typically experience-rated. This means that producers with good records of environmental protection pay lower premiums. This experience rating mitigates the misalignment of incentives because a forward-looking producer will take potential changes in premium levels into account when making decisions that affect the environment.

Blanket bonds

As mentioned earlier, the BLM and many state regulators allow natural gas producers to post a single "blanket" bond that covers all wells owned by the company. If a producer owns a small number of wells (e.g., less than 10), then blanket bonds increase incentives for prudent environmental stewardship because the producer stands to lose the entire bond if damages occur anywhere. In practice, however, many producers own large numbers of wells. Moreover, although the industry is relatively unconcentrated, with more than 15,000 natural gas wells drilled annually in the United States (U.S. DOE 2014b, Table 5.2), this has often led to cases in which the available blanket bond was inadequate to pay for necessary cleanups on multiple sites (GAO 2010). For example, in 2001, the Emerald Restoration and Production Company went

[21]West Virginia Legislature H.B. 401, §22-6A-15. "Performance Bonds: Corporate Surety or Other Security," December 2011.
[22]South Dakota Legislature, SB 1, 45-9-14, "An Act to Revise the Provisions Regarding Plugging and Performance Bonds for Oil and Gas Wells," March 2013.
[23]Maryland Legislature, SB 854, Chapter 568, "Environment – Gas and Oil Drilling – Financial Assurance," May 2013.

bankrupt, leaving behind 120 wells that needed to be plugged and the sites reclaimed. The company had posted a $125,000 bond, but this was not nearly enough to pay for expected expenses. To date, more than $2 million of public funds has been used for this cleanup (Oil and Gas Accountability Project 2005).

Incorporating observable measures of risk

Some states' minimum bond amounts depend on an observable measure of the level of risk.[24] The economic argument for this approach is that different well types have different levels of environmental risk. For example, deeper wells tend to be riskier because natural gas deposits at greater depths are under higher pressure, so more can go wrong during well construction, with more significant consequences. The advantage of differentiating wells according to their different levels of risk is that bond amounts can be smaller for wells with smaller risks. Moreover, using less general formulas for determining minimum bond levels also minimizes distortions in producer decisions concerning the type of wells to drill.

The problem with incorporating observable measures of risk is that it is difficult to decide exactly what criteria to use. With depth, for example, there is a counter argument. Whereas deeper wells are under more pressure, shallow wells also present risks because hydraulic fracturing occurs closer to groundwater reserves. In addition, every category of risk will likely have exceptions. For example, some deep wells are relatively safe because, for example, they are in locations far from populated areas and water resources, whereas some shallow wells are quite risky because of nearby groundwater reserves or some other characteristic. One advantage of the current federal system, which does not distinguish by depth or other measures of risk, is that it is easy to administer. In contrast, many states provide substantial discretion in setting bond amounts. Although in theory, negotiating bond amounts on a well-by-well basis could lead to more efficient bond amounts, in practice it adds to the overall economic cost of bonding requirements because it causes the diversion of resources to non-productive uses, such as negotiating with regulators over bond amounts.

Summary and Conclusions

The immense supply of natural gas made possible by hydraulic fracturing and other technological advances offers enormous potential benefits. The challenge for U.S. policy makers is determining how to facilitate the continued development of these valuable resources while ensuring environmentally safe drilling and adequate site reclamation once production has been completed. This is particularly difficult in the natural gas market because production occurs at thousands of geographically dispersed wells, which makes direct monitoring extremely expensive and raises the issue of moral hazard.

This article has reviewed the regulatory approaches available to U.S. policy makers for mitigating moral hazard in this sector. Tort liability, direct regulation, and mandatory insurance are all likely to continue to play important roles in both federal and state regulatory systems. In addition, bonding requirements can be an important complement to these approaches. Although they have important limitations, bonding requirements are well suited

[24]For example, in Texas, bond amounts are based on the depth of the well.

for addressing many of the relevant environmental risks and are effective for ensuring that private funds are available to pay for site reclamation when production is completed. Bonds provide a source of funds for cleanups when necessary and, more importantly, an incentive for producers to make efforts to avoid environmental damages altogether.

Appendix Table 1 Existing State Bonding Requirements

State	Bond Amount Depends on Well Depth	Minimum Bond Amount Per Well ($)	Blanket Bond Amounts ($)
Alabama	Y	5,000–50,000	100,000
Alaska	N	100,000	200,000
Arizona	Y	10,000–20,000	25,000–250,000
Arkansas	n.s.	Not to exceed $100,000	n.s.
California	Y	15,000–30,000	100,000–1,000,000
Colorado	Y	10,000–20,000	60,000–100,000
Delaware	N	n.s.	n.s.
Florida	Y	50,000–200,000	1,000,000
Georgia	N	not to exceed $50,000	50,000
Idaho	N	10,000	25,000
Illinois	Y	1,500–3,000	25,000–100,000
Indiana	N	2,500	45,000
Kansas	Y	7,500–30,000	30,000–45,000
Kentucky	Y	500–5,000	10,000–100,000
Louisiana	N	n.s.	n.s.
Maryland	N	Not to exceed 100,000	Not to exceed 500,000
Michigan	Y	10,000–30,000	100,000–250,000
Mississippi	Y	10,000–50,000	100,000
Missouri	Y	1,000–4,000	20,000–30,000
Montana	Y	1,500–10,000	50,000
Nebraska	N	5,000	25,000
Nevada	N	10,000	50,000
New Mexico	Y	5,000–12,500	50,000
New York	Y	2,500–250,000	25,000–2,000,000
North Carolina	Y	5,000 + 1 dollar per foot	n.s.
North Dakota	N	50,000	100,000
Ohio	N	5,000	15,000
Oklahoma	N	Plugging cost	25,000–50,000
Oregon	Y	10,000–25,000	100,000–no limit
Pennsylvania	Y	Varies	250,000–600,000
South Dakota	N	5,000	20,000
Tennessee	N	2,000	10,000
Texas	Y	2 dollars per foot	25,000–250,000
Utah	Y	1,500–60,000	15,000–120,000
Virginia	N	10,000	25,000–100,000
Washington	N	Not less than 50,000	Not less than 250,000
West Virginia	N	50,000	250,000
Wyoming	Y	10,000–20,000	75,000

Source: GAO (2010); Groundwater Protection Council ND; Pennsylvania Legislature, H.B. 1950, §3225; West Virginia Legislature H.B. 401, §22-6A-15.; Maryland Department of Energy, ND. See also Gerard and Wilson (2009) for additional discussion of bonding requirements in California, Texas, and Illinois.

References

Associated Press. 2012. Gas well spews polluted water. New York Times, April 20.

Boyd, James. 2001. *Financial responsibility for environmental obligations: are bonding and assurance rules fulfilling their promise? Discussion paper.* Washington, DC: Resources for the Future.

Brown, John P. 1973. Toward an economic theory of liability. *Journal of Legal Studies* 2: 329–349.

Calmes, Jackie, and Helene Cooper. 2010. BP chief to express contrition in remarks to panel. New York Times, June 16.

Carnevale, Anthony P., Jeff Strohl, and Michelle Melton. 2011. *What's it worth? The economic value of college majors.* Washington, DC: Georgetown University Center on Education and the Workforce.

Department of Energy, Energy Information Administration. 2013a. Annual energy outlook 2013.

———. 2013b. Levelized cost of new generation resources in the annual energy outlook 2013.

———. 2014a. Henry Hub natural gas prices. http://www.eia.gov/dnav/ng/hist/rngwhhdW.htm.

———. 2014b. Monthly Energy Review July 2014.

Environmental Protection Agency. 2012. Oil and natural gas sector: new source performance standards and national emission standards for hazardous air pollutants reviews. 40 CFR Part 63; Washington, DC: EPA.

Gerard, David. 2000. The law and economics of reclamation bonds. *Resources Policy* 26: 189–197.

Gerard, David, and Elizabeth J. Wilson. 2009. Environmental bonds and the challenge of long-term carbon sequestration. *Journal of Environmental Management* 90 (2): 1097–1105.

Government Accountability Office. 2010. Oil and gas bonds: bonding requirements and BLM expenditures to reclaim orphaned wells. GAO-10-245; Washington, DC: GAO.

Gram, Dave. 2012. *Vermont becomes first state to ban hydraulic fracturing.* Associated Press.

Greenstone, Michael. 2010. A built-in incentive for oil spills. Politico, June.

Ground Water Protection Council. ND. State bonding requirements for oil, gas and class II wells. Oklahoma City: GWPC.

Kellogg, Ryan. 2011. Learning by drilling: interfirm learning and relationship persistence in the Texas oilpatch. *Quarterly Journal of Economics* 126: 1961–2004.

Maryland Department of Energy, Office of the Secretary. ND. untitled memo. http://www.mde.state.md.us/programs/Land/mining/marcellus/Documents/Meetings/Requested_Information.pdf.

Massachusetts Institute of Technology. 2011. The future of natural gas: an interdisciplinary MIT study. Cambridge, MA: MIT Press.

Mitchell, Austin L., and Elizabeth A. Casman. 2011. "Economic incentives and regulatory framework for shale gas well site reclamation in Pennsylvania. *Environmental Science and Technology* 45: 9506–9514.

Muller, Nicholas Z., Robert Mendelsohn, and William Nordhaus. 2011. Environmental accounting for pollution in the United States economy. *American Economic Review* 101 (5): 1649–1675.

Oil and Gas Accountability Project. 2005. "Oil and gas at your door? A landowner's guide to oil and gas development." Durango, CO: Oil and Gas Accountability Project.

Olmstead, Sheila M., Lucija A. Muehlenbachs, Jhih-Shyang Shih, Ziyan Chu, and Alan J. Krupnick. 2013. Shale gas development impacts on surface water quality in Pennsylvania. *Proceedings of the National Academy of Sciences* 110 (13): 4962–4967.

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

Pitchford, Rohan. 1995. How liable should a lender be? The case of judgment-proof firms and environmental risk. *American Economic Review* 85: 1171–1186.

Richardson, Nathan, Madeline Gottlieb, Alan Krupnick, and Hannah Wiseman. 2013. The state of state shale gas regulation. Resources for the Future Report, June.

Ringleb, Al H., and Steven N. Wiggins. 1990. Liability and large-scale, long-term hazards. *Journal of Political Economy* 98 (3): 574–595.

Rotman, David. 2012. King natural gas. MIT Technology Review, August.

Shavell, Steven. 1984a. A model of the optimal use of liability and safety regulation. *Rand Journal of Economics* 15 (2): 271–280.

———. 1984b. Liability for harm versus regulation of safety. *Journal of Legal Studies* 13: 357–374.

———. 1986. The judgment proof problem. *International Review of Law and Economics* 6: 45–58.

———. 2004. *Foundations of economic analysis of law*. Cambridge, MA: Belknap.

Shogren, Jason F., Joseph A. Herriges, and Ramu Govindasamy. 1993. "Limits to Environmental Bonds". *Ecological Economics* 8 (3): 109–133.

Tennille, Tracy. 2012. "U.S. to Set Rules for Fracking on Federal Land," Wall Street Journal, May 4.

Weisman, Jonathan, and Guy Chazan Guy 2012. "BP Halts Dividend, Agrees to $20 Billion Fund for Victims", Wall Street Journal, June 16.