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Governance of shale gas development: Insights from the Bloomington school of institutional analysis

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Abstract The boom in shale gas production has been accompanied by concerns that polycentricity, whereby multiple levels of government share regulatory authority, has resulted in an inefficient and ineffective governance. The Bloomington School of institutional analysis suggests otherwise. Drawing on the work of Elinor and Vincent Ostrom, we clarify a diverse regulatory response to shale gas development within federations may be appropriate depending on the physical context of shale gas development, local demand for economic development (including geology, geography, and the built environment), the regulatory capacity of local governments, uncertainty about the appropriate regulations to address externalities from shale gas production, and the extent of inter-jurisdictional coordination problems. We apply the framework to regulation of shale gas development two fracking federations: the US and EU. In each context, letting a thousand regulatory flowers bloom is more sensible than uniform standards.

Keywords Polycentric governance · Bloomington school · Fracking · Institutions · Private property

1 Introduction

Global natural gas production has increased substantially since the early 2000s as a result of fracking shale gas (Hausman and Kellogg 2015). Shale gas cannot be

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profitably mined using the conventional technique of drilling downward and relying on natural pressure to force the gas to the surface. The reason is shale is too impermeable. Fracking, a process that combines horizontal drilling with hydraulic fracturing of shale through injection of chemically-treated water into the rock, made production of shale gas economically profitable.[1]

The US has led the way in the shale revolution.[2] Its consequences include economic growth, job creation, windfall profits for public schools, and tens of billions in royalty payments to the owners of mineral rights (Black et al. 2018; Brown et al. 2016; Fetzer 2014; Feyrer et al. 2017; Weber 2012). Although much of the analysis of shale gas development suggests that there are economic benefits from production, a sizable literature also considers the possibility of a resource curse: that an increase in shale gas production makes an economy worse off (DeLeire et al. 2014; Maniloff and Mastromonaco 2014; Weber 2014). In addition, many studies focus on the environmental, ecological, and economic costs associated with hydraulic fracturing, including worse health near wells and lower property values in frack zones (Currie et al. 2017; Muehlenbachs et al. 2015).

The perception of unmitigated costs of hydraulic fracturing has led to substantial concern regarding governance of shale extraction. These concerns are exacerbated by the tremendous diversity of the regulatory response, especially in polycentric systems of governance such as the US and EU, where there are multiple levels of government that share regulatory authority over shale gas development.[3] In the US context, one cause for concern is the perception that federalism has resulted in a patchwork of disparate regulations of shale gas development, with some US states pushing ahead with shale production and others banning it (Warner and Shapiro 2013; Wiseman 2010). The American regulatory regime has even been depicted as an institutional and regulatory Wild West, harkening back to the image of the American west during the nineteenth century as a time of disorder, conflict, and violence (Rabe and Borick 2012).[4] More favorable accounts of the American shale boom suggest that the system has not sufficiently addressed risks associated with fracking (Small et al. 2014). Governance of fracking in Europe is open to a similar critique, as the member countries enjoy substantial autonomy to regulate, and to prohibit, hydraulic fracturing even though the supranational EU government could assert authority to regulate shale gas development, including by establishing uniform standards. Like the US, the responses

[1] For an excellent overview of the economics of fracking, see Fitzgerald (2013).

[2] There is also a tremendous amount of oil in shale, but fracking shale oil has not revolutionized energy markets like shale gas. Thus, the "shale revolution" or "shale era" generally refers to fracking shale gas. Although it is not our focus, the analytical framework developed readily applies to the case of regulation of shale oil.

[3] We follow Eusepi and Wagner (2010) and Wagner (2005) in distinguishing between polycentric and decentralized orders. Polycentrism is defined by contestation and competition at multiple levels of government, while decentralized governance may simply involve implementation at local levels, without meaningful self-governance. Our interest is in political regimes where there is legitimate self-governance by local units in federal systems, which is the essence of a polycentricity.

[4] Economists interested in the American west have done much to dispel the notion that it was disorderly, mostly because institutions emerged spontaneously to reduce conflict (Anderson and Hill 2004; Umbeck 1977). The accounts of the shale boom as a Wild West do not necessarily correspond to the reality of the American west, which was quite orderly for reasons anticipated by the economics literature on anarchy. One of the reasons why order is common in such contexts is because institutions often arise spontaneously to resolve economic problems (Clark and Powell 2017; Palagashvili et al. 2017; Powell and Stringham 2009).

of the constituent members of the European federation have varied dramatically, with some pressing ahead with production and others banning it.

Existing studies critical of fracking federalism hone in on differences in the regulatory stances taken by local regulators in making an argument that the political institutions governing fracking are inefficient. We argue that this view is erroneous. Hydraulic fracturing regulation is efficient when it responds effectively to market failures, such as an environmental externality. Although recent work suggests that the state response in the US varies too much in order to be justified from an efficiency perspective (Mason et al. 2014; Richardson et al. 2013), we contend that variation in policy approaches should not be interpreted as direct evidence of regulatory failure. Indeed, a diversity of responses by regulators and policymakers will be efficient whenever different jurisdictions experience different degrees and kinds of market failure. Moreover, there are several justifications for regulatory diversity within a polycentric system of governance beyond the extent of market failure, such as differences in preferences for economic growth and or epistemic function of polycentrism, which is to generate knowledge via localized experiments about how to best regulate shale gas development to address its social costs.[5]

Substantively, we show why a diversity of regulatory responses, rather than a uniform policy imposed by the central government in the US or EU, is the most appropriate way to regulate shale gas development. This is for several reasons, including significant variation in the geological, geography, and built infrastructure where shale extraction takes place, the tremendous diversity of preferences regarding the acceptability of shale gas development, uncertainty regarding the appropriate ways to regulate hydraulic fracturing, the substantial capacity of local political units in each federation to regulate hydraulic fracturing, and few clearly identifiable interjurisdictional coordination problems that would justify uniform standards imposed by the central government. Rather than a cause for consternation, the diversity of regulatory responses in these federations generates knowledge of how to best regulate shale gas development, acknowledges the diversity of preferences over shale development, and encourages participation in the policy process from multiple levels of government.

Our article contributes to several literatures. One literature considers the benefits and costs of polycentric governance of natural resources. Our conceptual framework extends on studies of federalism of watershed management (Blomquist and Schlager 2005; Heikkila et al. 2011; Schlager et al. 2012), as well as studies contemplating the appropriateness of federalism of climate change policy (Rabe 2011), by considering explicitly the benefits and costs of uniform versus diverse rules governing development within a polycentric system. We also more carefully consider both the benefits and costs of polycentrism. Recent studies suggest uncontrolled costs of hydraulic fracturing in polycentric systems of governance, especially the US (Burger 2013; Craig 2013; Osofsky and Wiseman 2014; Rabe 2014; Warner and Shapiro 2013; Wiseman 2009, 2010). Although several studies offer a nuanced perspective on hydraulic fracturing regulation (Spence 2013a, 2013b, 2013c), existing studies do not provide an adequate accounting of all the relevant benefit and cost categories of polycentric governance of shale gas development. in work which bears several affinities to our own, Holahan and

[5] In this regard, the epistemic and generative functions of polycentric governance parallel the epistemic role of prices in Austrian economics.

Arnold (2013) use insights from Elinor Ostrom's perspective on the commons to understand shale gas development. However, they do not explicitly consider why a diversity of regulatory responses may be justified or acknowledge the generative and epistemic properties of polycentric governance of shale gas development. In addition, while several studies provide insight into the local politics of hydraulic fracturing, including why some communities decide to ban fracking (Arnold and Holahan 2014; Arnold and Long 2018; Arnold and Neupane 2017), our paper provides an economic justification for such self-governance.

Our perspective also complements work on conventional oil and gas development by Libecap (1989a, 1989b), Libecap and Smith (1999, 2002), and Libecap and Wiggins (1985). These works emphasize the importance of transaction costs (which, among other things, include the costs of bargaining between parties, monitoring adherence to contractual obligations, and enforcing property rights) in evaluating alternative institutional arrangements to govern mineral extraction. The transaction cost perspective shares important affinities with ours, as it suggests that the optimal contract choice to govern oil and gas development will vary with local conditions. However, existing work on oil and gas contracts focuses on solutions to production-relevant externalities, especially a pumping race, while we emphasize the importance of polycentric political institutions in generating knowledge about how to regulate the development of minerals, as well as consider externalities beyond production-relevant ones.

Finally, we acknowledge the importance of the property rights regime governing minerals. The US is unlike most countries in that minerals can be severed from the surface estate and that the minerals can be publicly or privately owned. The severability of the surface and mineral estate, along with mixed public or private ownership of minerals, may influence the values of leases (Fitzgerald 2010, 2012). In addition, private ownership encourages innovation, as well as creates incentives for local collective action to support oil and gas development (Murtazashvili 2017). Private ownership of minerals also provides further justification for self-governance of minerals. In analyzing the foundations of effective property rights, Williamson (2009) emphasizes that private property institutions often develop locally in response to economic problems through a spontaneous process. One of the consequences is that there will be substantial variation in the quality of informal private property institutions, but also in the extent to which legal private property institutions recognize spontaneously-arising institutions. It stands to reason that variation in the regulatory and institutional response to oil and gas development makes more sense when there is substantial variation in the extent to which local jurisdictions have a history of private property rights to mineral extraction. Such historical legacies suggest that self-governance will be more effective in managing the process of development of minerals.

2 An overview of hydraulic fracturing

The geological features of shale gas make it economically unprofitable to extract using methods to extract conventional oil and gas, which involves drilling downward and relying on natural geological pressure to release oil and gas. The economics of shale changed when drillers experimenting with the Barnett Shale in Texas figured out how to profitably frack shale gas. Hydraulic fracturing is not a new technology, nor is

horizontal drilling, but the combination of the two techniques, along with figuring out the right mix of chemicals to treat the water used in the machines that fracture shale, had effects similar to new technology (Fitzgerald 2013).

The impermeability of shale also provided a solution to one economic problem that confronts development of conventional oil and gas. Shale gas, like most natural resources, has common-pool features. A common-pool resource is defined by non-excludability and divisibility. Non-excludability refers to the inability to exclude users from a resource. Divisibility means that the resource can be used up (E. Ostrom 2005). These features make these types of resources especially susceptible to the tragedy of the commons.

Although shale gas and conventional oil and gas bear some important similarities, the challenges of resource governance differ. One of the main challenges with conventional oil and gas is racing to extract resources from a pool of oil or gas they can access from the surface land. Since the oil and gas can be extracting using simple downward drilling techniques, the resource itself has the potential to be overused (Libecap and Smith 1999, 2002). The solution to these conventional oil and gas wells is unitization, which is a contracting arrangement that establishes property rights to common oil pools (Libecap and Wiggins 1985; Wiggins and Libecap 1985). Unitization establishes a property right for users in common. Although unitization is a potential solution, one of the challenges with property rights is that distributive conflict can often undermine the emergence of an effective property regime (Libecap 1989b).

Pumping races are unlikely to take place in the shale industry due to the higher entry costs. Hence, unitization agreements will be less prevalent than in the case of oil. However, shale gas extraction could be prone to holdout problems because to maximize the value of their rights, shale producers will have to attain economies of scale in the size of shale wells. Often, the rights over surface land and those over mineral resources are separated, which constitute a severed estate system (Ellickson 1993). The severing of estates has gone on for centuries in the US and is intertwined in the history of US land laws (Murtazashvili 2013). Under such a system, shale gas companies must deal with large numbers of landowners. Holdouts can vastly increase the transaction costs and, therefore, negatively affect the profitability of the industry. Forced pooling, which requires landowners to lease land when surrounding land has been leased, is one institutional solution to this problem. In this way, it reduces the transaction costs of bargaining with a holdout who opposes hydraulic fracturing or who wants to get a better deal from the gas companies.

Even assuming there are solutions to these holdout problems, there are still going to be externalities with shale gas development. Both conventional and unconventional oil and gas extraction exhibit several types of negative economic externalities in varying degrees.[6] These externalities can be divided into several types: production and consumption externalities; point and nonpoint externalities; and contemporaneous and intertemporal externalities. For reasons noted, the local production externalities arising from a pumping race do not pose as much of a challenge to shale gas extraction than with conventional oil and gas extraction because of the geological features of shale gas

[6] We do not consider positive externalities. There are certainly positive externalities with the oil and gas industry, which is one reason why there is substantial public investment in university extension programs devoted to research how to improve mining techniques (Clay and Wright 2010).

production. However, shale gas differs from conventional oil and gas in that there is perhaps more of a challenge with local nonpoint externalities, especially groundwater and surface water contamination (Holahan and Arnold 2013). Shale gas development also involves local externalities arising from water use, earthquakes, and use of public infrastructure that may be more severe than in the case of conventional oil and gas extraction. There are also global nonpoint consumption externalities, such as those arising from release of fugitive methane, that are more specific to shale gas development than conventional oil and gas extraction, although both conventional and unconventional extraction of oil and gas involve intertemporal externalities, as the resources will ultimately be used up, making future generations worse off.

Our goal is not to debate the extent of these externalities. Rather, the key point is that there are differences in the severity of the type of externalities from fracking compared to conventional oil and gas extraction. These differences provide a justification for policy experimentation; they are the rationale for the epistemic function of polycentrism.

3 Polycentric governance of hydraulic fracturing: A framework

A large literature, dating back to at least the seventeenth century political economist Thomas Hobbes, suggests that the law should come from a centralized source. Hobbes hypothesized that conflict is the necessary outcome whenever the creation and enforcement of law are not centralized, proposing an all-powerful central government—which he called Leviathan—to hold people in check. Subsequently, proponents of legal centralism emphasized the virtues of standardized legal rules. According to these perspectives, the centralized state emerged and exists in order to provide public goods, including uniform legal rules, economic institutions, and collective defense (Brewer 1990; Johnson and Koyama 2014; North and Thomas 1973; Sened 1997).

A contrasting perspective suggests that polycentric governance might have some virtues after all.[7] Hadfield and Weingast (2012, 2013) consider the origins of law, in particular the importance of decentralization of enforcement of law. They define "law" by an identifiable, authoritative body that provides a unique, clear, and noncontradictory normative classification that is prospective and reasonably stable and provide a general framework to understand why law can be polycentric. There is also a large literature that highlights the benefits of dividing sovereignty among multiple levels of government (Weingast 1995, 1997). This literature suggests that the extent to which the central government is able to provide public goods, including protection of private property rights, is a question not simply of state capacity, but of its ability to credibly commit to non-predatory behavior (Leeson and Suarez 2016; North and Weingast 1989; Root 1989). One source of constraints is autonomy of local governments, which provides a bulwark against the centralized state. In addition, economists have long seen federalism as desirable because it increases the efficiency of public goods provision as

[7] One of the virtues of polycentric governance, as conceptualized of by Vincent Ostrom (2008), is that is provides a political foundation for self-governance. A complementary perspective conceptualizes of self-governance as order which occurs in stateless societies, or without much role for a state (Leeson 2006, 2011, 2014). Each perspective emphasizes that the central government is not the only source of order in society, as well as recognizes a role for spontaneous order (Boettke and Coyne 2005).

long as people are able to "vote with their feet" in response to public policies with which they disagree (Epple and Zelenitz 1981).

The argument for polycentric systems of governance goes back to Tiebout (1956), who argues that, under a set of assumptions—including competition between local public good providers, perfect mobility of the consumer-voters, and perfect information—that such a system would be able to provide the efficient level of public goods and match individuals with their preferred combinations of publicly provided services. Ostrom et al. (1961) conceptualize polycentric governance as shared authority among multiple, autonomous, overlapping decision making units, all part of a single, broader political jurisdiction. Subsequent research has shown that polycentric governance is often an appropriate institutional response to the challenge of managing natural resources for reasons such as the importance of local experimentation and better fit of regulations to local conditions (E. Ostrom 1990, 2005, 2009).[8] Moreover, this literature acknowledges that central government intervention can undermine resource governance outcomes (Arnold 2015).

A growing literature relates polycentric governance to sustainable use of natural resources. The challenges with natural resources, such as farms, forests, pasture, and fisheries, is that they have the characteristic that they have features of a common pool (Cole et al. 2014; McGinnis and Ostrom 2014). Many of the initial studies of polycentric resource governance focused on informal systems for managing access to common-pool resources (E. Ostrom 1990). Yet the approach offers insight into governance more broadly. The Bloomington School of institutional analysis, as it came to be known, is a method for analyzing formal and informal institutions of governance and is not limited to analysis of natural resources (Aligica 2017a, 2017b; Aligica and Boettke 2009; Aligica and Tarko 2012, 2013). However, as our interest is in governance of shale gas production, we confine our attention to one of its initial applications, which is governance of extraction of resources from a common pool.

The virtue of polycentric governance of resources include tailoring solutions to local conditions and encouraging adaptation and innovation (E. Ostrom 2005). This is due, on the one hand, to the fact that local units have decision-making autonomy, which allows for a better utilization of knowledge of local circumstances. On the other hand, the freedom of the consumer-voters to "vote with their feet" introduces incentives for the local providers to supply the demanded bundle of goods and services.

But polycentric orders come at a cost. Among their main shortcomings are the limited capacity to regulate economic activities, the possibility of interjurisdictional externalities, and that of competition between local jurisdictions to attract investment that can undermine a municipal tax base (Boettke et al. 2011). For example, Maniloff and Manning (2017) develop a theoretical model of optimal severance taxes on oil production in a polycentric order. They find that the optimal tax rate is a function of the relative size of the oil and gas reserves within a region as well as the relative extraction costs within the same region. Local governments can increase their revenues from the taxation of natural resources by encouraging and/or financing investment that lower the

[8] The importance of local experimentation is also theme in the public choice literature on governance. Both Hayek (1945) and Coase (1960) suggested governments face information problems that require consideration of decentralized solutions. Stringham and Zywicki (2011) articulate the affinities between Hayek's perspective on governance and the literature on polycentric governance.

costs of access to nonrenewable resources. These results further illustrate that rather than unambiguously good or bad, the appropriateness of polycentric governance will depend on its context. Regulation of shale gas extraction provides an important opportunity to examine the benefits and costs of polycentric governance of a valuable natural resource in a rapidly changing technological, economic, and political environment.

Another limit of polycentric governance is that the local units may not have the capacity to govern effectively. They may also be unable to provide public goods that could benefit multiple jurisdictions. In such situations, the local units often have to cooperate in an environment of self-help (Feiock 2004, 2007). Local tyranny is also a persistent concern when it comes decentralized governance, as the local decision-making bodies may be captured by local power brokers (Olken 2010). The public choice literature also recognizes that polycentric governance does not eliminate the traditional challenges of regulation, as local units can also be subjected to government failure (Boettke et al. 2011).[9]

This framework yields several important implications for the study of the governance of shale gas development.

First, a diversity of standards is more appropriate when there is greater variation in the physical context of shale gas extraction. By "physical context," we refer to differences arising from geology, geography, and the built environment—that is, public infrastructure. One of the key insights from Ostrom's (2009) work on governance of natural resources is tailoring governance to biophysical characteristics of the resource. Considerations of geological features is especially important in the context of hydraulic fracturing because the appropriate regulations depend in part on geography, such as proximity of hydraulic fracturing to groundwater and the availability of water for use in the fracturing process. For example, in the US, the geological features of shale (proximity to groundwater and water availability) differs in important ways in the shale-rich areas of Texas and Pennsylvania. More generally, there is major variation in water availability in shale-rich regions and different challenges to groundwater based on geology (Mauter et al. 2014; Vidic et al. 2013). The injection of water into the shale can result in seismic activity, although those effects vary with local geology: fracking in some areas has not led to much seismic activity, while in others, there have been many small earthquakes. Geography, such as the extent land is farmland versus rural versus urban, also has important implications for the extent to which fracking is allowed. So too does public infrastructure, which can help to overcome challenges of geology and geography. For example, infrastructure to move regionally can mitigate challenges arising from water availability in a region and may influence the benefits and costs of polycentric governance of shale gas development.

Second, diverse regulatory responses to hydraulic fracturing are more appropriate when there is greater diversity of local preferences over the tradeoff between economic productivity and environmental protection. Public perceptions can be divided into a growth orientation versus an environmental protection orientation (Inglehart 1997; Molotch 1976; Molotch and Logan 1987). The US is a large and heterogeneous country

[9] Despite the public choice criticism of polycentric governance, much of the approach is based in part on insights from earlier architects of public choice, especially Hayek (Boettke et al. 2014; Boettke and Coyne 2005).

characterized a high degree of ideological diversity and a variety of different sensibility with respect to environmental, social, and economic concerns. Although recent studies of hydraulic fracturing focus on environmental problems as the rationale for differences in policy (e.g., Richardson et al. 2013), differences in preference for economic growth is also a justification for variation in the regulatory stance of a local government.

Third, regulatory diversity is more effective when there is substantial policy uncertainty and need for regulatory experimentation. The need for experimentation is a standard argument in favor of polycentric governance (Rodden 2006). One of the defining features of shale is uncertainty about how to regulate it. Currently, uncertainty has been used as a justification to wait to extract shale. The rationale is that since shale will remain in the ground, its value will not be diminished by a more cautious approach (Goldstein et al. 2013). However, the uncertainty associated for shale just as easily provides a rationale for policy experimentation at the local level. Waiting to extract shale does not necessarily solve the informational problem of how to best regulate shale because identification of the appropriates regulations is to an extent an experience good.

A complementary way to think about the link between uncertainty and polycentricity is what we call the "regulatory knowledge commons." The concept of the knowledge commons refers to situations in which knowledge is useful precisely because it does not have property rights over it (Frischmann et al. 2014; Hess and Ostrom 2007). Such perspectives neglect how knowledge is generated, which is because of property rights, yet is certainly correct in that knowledge, once created, may have features of a public good. Knowledge of how to regulate an economic activity also has features of a public good: once discovered, regulators in other jurisdictions can borrow it. Our contention is that polycentrism generates a regulatory knowledge commons, that is, ideas about how to best regulate hydraulic fracturing.

Fourth, when the local units have greater information-gathering, monitoring, and enforcement capacity, the case for uniform standards is weaker. One of the defining features of governance is administrative capacity (Barnard 1938; Fukuyama 2013). The case for decentralization of political authority to regulate hydraulic fracturing is weaker when the local units in the polycentric system of governance lack sufficient capacity to monitor, evaluate, and disseminate information regarding shale production, as well as insufficient capacity to enforce rules regulating shale production.

Finally, the case for uniform standards is stronger when there are coordination problems involving interjurisdictional externalities. Environmental externalities often transcend jurisdictional boundaries. The clearest examples are the "global commons," such as global warming. In such situations, polycentric governance (the nation-state system) is often a severe constraint on governance (E. Ostrom et al. 1999; Young 2010, 2011). One of the challenges of decentralized governance is that resources may transcend boundaries. When they do, the local units must coordinate policies. In such situations of externalities that transcend boundaries, there is a stronger case for centralized governance. For example, global commons issues, such as global warming, may requires more centralized administrative solutions since the local units may have incentives to free ride on efforts by other units to limit these externalities.

To summarize, according to the framework, a diversity of regulatory responses within a federal system is more appropriate when there is variation in the physical context of shale extraction, variation in preferences for economic growth versus

environmental protection, substantial uncertainty regarding the appropriate regulations of hydraulic fracturing, local units have substantial regulatory capacity, and there are few identifiable interjurisdictional externalities.

4 Two fracking federations

We consider two fracking federations: the US and EU. We first consider the US, where the American federal system provides Congress with substantial authority to regulate issues that transcend the boundaries of a single state, while the states reserve regulatory powers that are not specifically given to the national legislature. Following the argument set forth in *The Federalist Papers*, the fundamental powers of the states are the police powers, which are the powers to provide for health, safety, and welfare. Although the pendulum of authority has swung toward the federal government since adoption of the US Constitution, the states remain formidable regulatory and political entities (Bednar et al. 2001; Bednar and Eskridge Jr 1994; Eskridge Jr and Ferejohn 1994). Generally speaking, the boundaries of Congressional authority are determined by the extent to which an activity has effects that transcend state boundaries, as interpreted by the US Supreme Court (Pickerill 2004).

On matters of oil and gas extraction, at least East of the Mississippi River, the Federal Government has played little to no role, leaving matters in the hands of local authorities. Nevertheless, given its proactive role in other regulatory areas, the Federal Government could likely step in in case of necessity. One such possibility would be in case of failure of local government to address interstate externalities. Yet this is unlikely as a practical matter. The two most relevant cases of this nature resulting from the extraction of shale gas are the pollution of groundwaters and the phenomenon of fugitive methane. Both are unlikely to require the intervention of a centralized regulatory authority. Groundwater pollution could at most require the coordination of a few local authorities. Hence, coordinating policy responses should not be problematic. Fugitive methane could potentially constitute an issue of interstate and even global relevance but, as of today, the magnitude of the phenomenon has remained small, in part because shale gas producers have an incentive not to waste that valuable resource. Perhaps due to these factors, regulation of hydraulic fracturing in the US has remained decentralized.

The regulatory response in Pennsylvania and New York illustrates the potential for major differences in regulation of hydraulic fracturing despite both states lying atop the Marcellus Shale. The response in Pennsylvania has been to allow hydraulic fracturing to proceed, while adapting existing regulations to the current context of shale extraction. Part of the rationale for state regulation was the considerable number of municipal governments in the state: Pennsylvania has 67 counties and over 2500 municipal governments, which raise the possibility of many different regulations of shale and hence a coordination problem.

One coordination issue is that there may be a patchwork of communities that allow fracking. Indeed, several communities in Pennsylvania banned fracking, with the first ones coming about in 2010. There were also efforts to regulate fracking directly. In response to the potential coordination problem, the government of Pennsylvania responded with Act 13. One of the key features of Act 13 to restrict the ability of local

governments to regulate hydraulic fracturing. Act 13 also established an established an impact fee, with revenue distributed to local governments, to internalize the external costs to local government infrastructure from shale production.

In New York, gas companies signed leases with landowners in anticipation of a shale boom, as New York is also shale rich. However, in 2009, then-Governor David Paterson authorized an impact evaluation of hydraulic fracturing for the state of New York. After willing election in 2010, Governor Andrew Cuomo issued a continuation of the study. Today, the impact study has become a de facto ban on shale production, with the main rationale being that there is unreasonable uncertainty about the health risks of fracking. Many local governments in New York have also banned hydraulic fracturing even though there is a statewide ban, with variation in responses reflecting the strength of social networks and policy entrepreneurs on either side of the fracking issue (Arnold et al. 2017; Arnold and Holahan 2014; Arnold and Neupane 2017). Several other states restricted hydraulic fracturing or considered prohibiting it.[10]

The US Environmental Protection Agency could assume a more proactive role in shale governance because of its interstate consequences but passed on chances to federalize regulation of hydraulic fracturing. The Energy Policy Act of 2005 exempted hydraulic fracturing from the (federal) Safe Water Drinking Act, which defers to the states regulation of hydraulic fracturing. The Fracturing Responsibility and Awareness of Chemicals (FRAC) Act, which was proposed in the House in 2009 and Senate in 2011 but never approved, would have required the EPA to regulate hydraulic fracturing and require disclosure of chemicals used in the hydraulic fracturing process.[11] Thus, there remains a diversity of regulatory responses to shale gas development, with very little in the way of a uniform set of standards, issued by the federal government, to govern the shale revolution.

The EU has political structure like the US, although the central government in the EU does not have as much regulatory or enforcement capacity as the US. Nonetheless, it can still assert authority over the member states. It is also an open question whether the EU ought to develop a uniform standards or to embrace the diversity of responses.

There is certainly an economic interest in shale gas production. Natural gas is about 25% of EU energy consumption and many countries rely on one source to important nearly all its natural gas. Europe also has substantial shale wealth, though not as much as the major players in North America (Canada and Mexico also have substantial shale reserves), Argentina, or China. Nonetheless, Europe has substantial shale. For example, the UK has enough shale gas to meet demand for decades. There is also the persistent issue of dependence on Russia for natural gas, including dealing with its state-owned gas behemoth, Gazprom.

Despite the economic incentives to get fracking off the ground, there has not been much production. American companies were drilling hundreds of thousands of wells a year at the height of the shale boom, while in Europe there were only around 100 a year during that time. The US has also seen a drop in energy prices as gas production increased from 1 to 30% of the US energy portfolio, while European prices have doubled (Fox 2013a).

[10] Richardson et al. (2013) provides a review of state-level regulation of the shale industry, including how these regulations vary across states.

[11] Warner and Shapiro (2013) and Osofsky and Wiseman (2014) describe in detail the federal option for regulation of hydraulic fracturing regulation.

Most of the challenge in Europe has been above-ground, or political. France was among the first countries to ban hydraulic fracturing in 2011 following widespread protest. Exploration licenses were granted in Denmark, Germany, Hungary, Netherlands, Poland, Romania, Spain, Sweden, and the UK. Bulgaria and Germany revoked licenses after the national government banned hydraulic fracturing. However, not all opposed fracking. Poland early on encouraged hydraulic fracturing.[12] Britain imposed a moratorium on hydraulic fracturing, although it lifted it after 18 months. The end of the moratorium has led to a rise in protest movements, as well as progress toward hydraulic fracturing.

The possibility of a patchwork regulatory regime led the European Commission to consider common regulations. In May 2013, the president of the EC announced plans for EU rules to ensure "safe and secure" extraction of shale in Europe. The regulations promised to ensure similar rules of the game while reassuring that public and environmental safeguards are in place. The policies, which were perceived as promoting hydraulic fracturing, were opposed by some leaders of the Green party (Fox 2013b).[13]

By early 2014, the EU backed off on the plan, leaving national governments in charge of regulation of hydraulic fracturing. Rather, EU proposed recommendations for environmental standards, such as minimum distances between hydraulic fracturing sites, and recommended water-management plants and efforts to capture methane, as well as to minimize flaring. There is also a compromise in place such that environmental impact assessments for shale gas projects will be prepared on a voluntary basis by member states (Fox 2014).

Currently, there are no binding standards imposed at the EU level. The EU policy governing hydraulic fracturing is for member states to follow minimum standards when applying or adapting legislation regulating hydraulic fracturing. Thus, the EC serves a similar role as the US EPA: to offer recommendations, while preserving self-governance of the local units in the polycentric system.

5 Uniformity, or letting a thousand regulatory flowers bloom?

Should we be concerned about the diversity of regulatory responses? Our analysis suggests not. First, there is tremendous variation in the physical context where drilling would occur. One geological source of variation is the proximity of drilling to groundwater. Proximity to groundwater is especially important with respect to disposal of chemically-treated water. In the United States, "deep injection wells" are regulated by the Environmental Protection Agency, but they are much more appropriate in some regions than others (Frohlich 2012; Rozell and Reaven 2012). For example, the deep injection wells are feasible around many of the wells in the Barnett Shale in Texas, although in much of Pennsylvania, they are not feasible because of the potential for

[12] Although Poland allowed fracking, and even encouraged it, the initial estimates of recoverable shale gas were something around 100 times the actual amount of recoverable shale gas (Blake 2014). Hence, there has not been and may never be a shale revolution in Poland, although the government certainly encouraged it.

[13] The European case demonstrates that centralization of regulation can just as easily be used to promote hydraulic fracturing as to constraint it. Indeed, in the US, typical rationale for Congressional regulation of interstate economic activities has been to *promote* economic activities and to limit the ability of states to constrain economic development (Weingast 1995). In the context of shale regulation, the presumption is often that a stronger federal role would constrain rather than promote hydraulic fracturing.

groundwater contamination. For this reason, much of the wastewater in Pennsylvania is disposed of in injection wells located in Ohio.

Another geological variable is availability of water. The availability of water is an important geographic variable because shale production is water intensive. In both the US and EU, there is tremendous variation in the availability of water. For example, Reilly et al. (2008) estimates that mean annual ground-water recharge in the United States varies from a minimum of 0 to 1 in. per year in such states as Arizona, South and North Dakota, Nevada, and Texas, to the 5 to 20 in. per year of New York, Massachusetts, Maine, and Pennsylvania, to the over 20 in. per year of the western regions of Oregon and Washington state and north-western Florida. In general, in the US, there is much less water in shale-rich areas west of the 98th meridian, the conventional dividing line between the eastern and western states. There are also major differences between context of the Barnett Shale in Texas, where extraction might put pressure on groundwater aquifers, and Pennsylvania, where there is no reasonable risk of a shortage of water (Reilly et al. 2008, p. 24). Among EU countries, the variation is also very large. For example, the annual average of freshwater availability per capita goes from a minimum of less than one cube meter in Malta and Cyprus to the almost twenty cube meters of Finland and the over twenty-five of Croatia. France, Germany, Italy, Spain, and the United Kingdom all have less than three cube meters per capita, while Austria, Greece, Ireland, Netherlands, and Portugal have between six and twelve (Eurostat 2018).

One issue to keep in mind is that the water availability issue depends in part on infrastructure to get water from one place to another. The better the infrastructure, the less binding the rainfall constraint. In the US, there is already a massive infrastructure in place to move water around in the arid west. Much of this reflected rent-seeking historically, but a consequence today is that there is much water used in that region of the US. For example, water use is about 1% of agricultural use of water (Hitaj et al. 2017). Better infrastructure might strengthen the case for uniform standards, although there is still substantial cost of transporting water, and so regional variation in water quality will still suggest that policies should vary locally, or at least regionally.

Geology also provides a rationale for a diversity of regulatory responses to address seismic activity caused by fracking. In the US, there have been hundreds of micro-quakes in Oklahoma (Hand 2014). There have been few reports of seismic activity in Pennsylvania. Fracking has also gone on in Oklahoma without delay. In contrast, in the UK, a small earthquake led to an 18-month moratorium on fracking even though it caused no damage. The differences in the magnitude of seismic activities, as well as clear variation in risk preferences for addressing earthquakes, serves to further justify a diverse regulatory response.

An important geographic issue is whether shale is beneath agricultural or non-agricultural land. It may make the most sense to frack on agricultural land because the externalities are less costly (Rakitan 2018). The idea is that there are fewer people on agricultural land and hence to minimize externalities (such as health-related ones), it makes sense to focus fracking underneath or near farms. Thus, geological variation would further suggest regulatory responses will vary.

The diversity of preferences in these federations provides a second justification for regulatory diversity. When preferences are more diverse, polycentric governance is more likely to produce public policies at the local level that reflect the preferences of voters. There are several dimensions of diversity of preferences relevant in the context

of hydraulic fracturing, including diversity of opinions regarding the ecological and environmental consequences of hydraulic fracturing, diverse preferences about the importance of economic growth and development, and diversity of deeper constitutional principles, such as a belief in local autonomy.

The local units in the US and EU vary substantially on each of these dimensions. In terms of preferences for hydraulic fracturing, there is substantial variation in the US states. For example, in New York, there is a majority that oppose hydraulic fracturing, while a clear majority in Pennsylvania support hydraulic fracturing. There is more support among Republicans for hydraulic fracturing. Independents tend to be split (Kriesky et al. 2013).

Differences in economic conditions also suggest there will be different preferences over the regulation of shale gas extraction. In general, income levels seem to be a good predictor of support for environmental regulation (Davis and Fisk 2014, p. 4). The causal mechanism behind this has not been established in the literature, and the high degree of correlation between income, educational level, and ideological concerns murk the issue even more (Kahn 2002). With respect to the case of shale gas regulation, the evidence is mixed. For example, Boudet et al. (2014) find a negative, but statistically insignificant, correlation between income and support for fracking and Davis and Fisk (2014) find a positive, but also insignificant, effect of income on support of regulating shale gas extraction.

There is clear variation in the economic situation in different communities in the United States. These differences are expected to translates into differences in preferences over the tradeoff between economic development and environmental concerns under the reasonable assumption that a poorer economy will place more of a premium on economic growth, while as wealth increases, communities place a higher premium on a cleaner environment (Inglehart 1997).

There is also a great deal of economic heterogeneity among the EU countries. For example, decentralized governance would allow France to respond one way to hydraulic fracturing opportunities based on the economic situation and to allow Poland, another country rich in shale, to respond in a potentially very different manner. The support for fracking Poland compared to, say, France, may simply reflect the level of development.[14]

There are also significant differences in beliefs about constitutional norms at the state level in the US. For example, many states tied their own hands through constitutional amendments that prohibited the ability of state officials to use land for private development after the US Supreme Court decided to allow government to do just that.[15] Such changes suggest the importance of state constitutional principles in relationship to economic development. These differences in constitutional principles are even more apparent in Europe. For example, the precautionary principle in France exemplifies important variation in preferences about environmental risks.

EU Eurobarometer survey evidence also suggests a diversity of preferences for shale gas development in member countries (European Commission 2013). The EU public wants coordination but also desires local autonomy to prohibit hydraulic fracturing.

[14] There is also the fact that France imports nearly all its oil and gas already, which has led to investment in nuclear energy. Hence, the opportunity costs of banning fracking in France is much lower than in Poland.

[15] In *Kelo v. City of New London*, the Supreme Court upheld taking land from a citizen to give it to a corporation, interpreting this taking as "public purpose" because it might result in economic development.

This evidence suggests not only a diversity of preferences, but also broad support for polycentric governance of hydraulic fracturing in Europe.[16]

A third broad justification for diverse regulatory standards is the uncertainty associated with how to best regulate shale gas development. Part of this uncertainty derives because there are differences between conventional and unconventional gas extraction regarding the appropriate regulatory and institutional response. Thus, it is unclear what kind of regulations are "optimal."

One option is to deal with uncertainty with precaution, which has been used to justify bans on hydraulic fracturing. Such precautionary beliefs would provide a justification for diverse regulation, as it is one way to regulate out of many possible ones. A second way to proceed is through policy experimentation. One of the benefits of polycentric governance is exactly that it encourages such experimentation. In addition, polycentric governance facilitates opportunities for local government to implement similar regulations that work through a decentralized process of policy diffusion (Shipan and Volden 2006). A local diffusion process reduces the stakes of policy mistakes compared to centralized regulation.

The technological aspects of shale suggest that policy experimentation may be desirable once shale development proceeds. Effective regulation requires some degree of knowledge pertaining the phenomena and processes being regulated as well as the dynamic effects of the regulation itself on the behavior of the regulated agents. Acquiring this knowledge takes time and is more likely to be achieved if regulators go through a process of trial and error. Polycentric systems facilitate this trial and error while also generating a positive feedback mechanism that encourages error-correction.

Another reason for policy experimentation is that the conventional gas and oil institutions may not be directly applicable to shale. Much of the literature on conventional gas and oil focuses on unitization, which solves the problem of a pumping race. The challenges in the context of shale include groundwater contamination,[17] fugitive methane, and issues involving use of public infrastructure, workplace safety, and disaster response. By facilitating policy experimentation, polycentric systems of governance can facilitate emergence of a more effective regime to deal with these outcomes.[18]

The regulatory capacity of the American states and the EU member states also provide a powerful justification for a diversity of regulatory standards. In the US, the state governments are formidable regulatory units. While it is true that the federal government has a vast reach, the state and local governments in the US have a tremendous amount of regulatory authority and regulatory capacity to provide for

[16] The two goals (international coordination and local autonomy with respect to the regulation of fracking) are somewhat incompatible. Super-local coordination necessarily requires the alienation of some degree of autonomy at the local level. To the extent that some combination of the two is possible, this is more likely to be achieved within a polycentric system in which localities can decide whether to form a super-local authority.

[17] Groundwater contamination is of course not unique to shale gas extraction but is the potential side effect of well casing in general. We thank one anonymous referee for pointing this issue to our attention.

[18] The greater the probability that some disastrous event, the more justified a moratorium on what is perceived to be the potential cause. For the reasons discussed in the paper, this is very unlikely to be the case of fracking. The externalities of the latter tend to be concentrated within the relevant locality or regional at worst. In a case like this, adopting the precautionary principle at the national level has little benefits to it. The few local jurisdictions involved are better placed, both from a local knowledge and an incentive compatibility perspective, to deal with the issue.

health, safety, and welfare. At the local level, municipalities and towns regularly engage in zoning regulations, including regulation that influences shale development. For example, municipal governments in New York have asserted their authority by restricting hydraulic fracturing.

It is important to recognize that there are debates about the adequacy of state regulatory capacity. In Pennsylvania, doubts have been raised regarding the capacity of the state government to regulate shale, more specifically with respect to its ability monitoring compliance with regulations (Hamill 2014). However, the states have also proven capable of responding to the regulatory challenge imposed by increasing shale extraction. Act 13, which established new regulations on hydraulic fracturing, including an impact fee that is designed to compensate local governments for harms to infrastructure. The legislation also adapted existing oil and gas laws to unconventional oil and gas development.

The capacity to regulate shale gas development is even less of a question in the EU, where the local units are nation-states. The individual states can regulate shale if they choose to do so. Rather, the challenge to the EU may be lack of capacity of the EU to regulate hydraulic fracturing more effectively than the member states. Any effort to create uniform standards would likely be more challenging in the EU than in the US, although in the US, there would likely be substantial constitutional challenges to efforts by Congress to assert more regulatory authority over shale gas development.

Finally, interjurisdictional externalities do not in support uniform standards, with a few exceptions. The pollution aspects of hydraulic fracturing suggest the possibility of coordination problems that may require regulation at higher levels of government. Groundwater and surface water often transcend jurisdictional boundaries. It is for this reason that hydraulic fracturing could be regulated by the federal government in the US. In the EU countries, there may also be issues of shared water resources, although the intermingling of water resources and shared shale plays is probably less than in the US states.

Another coordination issue involves release of methane. When burned, natural gas is less environmentally costly than coal. However, venting methane into the atmosphere is worse for the global environment than burning either gas or coal. This global commons issue suggests the importance of higher level regulations to address what is a global externality.

While fugitive methane involves a coordination problem, there are market incentives to correct the problem that should mitigate this challenge. Oil and gas companies have incentives to reduce flaring or venting because it represents losses in the hundreds of millions of dollars on a monthly basis for the most extensively developed shale plays (Scheyder 2013). Since companies have incentives to capture methane rather than vent it or burn it, there will be incentives through markets to also limit the release of methane, either from flaring or from venting.

Despite such rationales for supra-local standards, it is still the gas that most groundwater externalities could be addressed by the states. For example, there could be setbacks from water and regulations on wells that consider geological conditions within the state. Alternatively, it may make more sense to deal with uniform standards for air pollution. The reason is that what is unsafe in terms of air pollution is not likely to vary with physical context. Indeed, in the US, the one area where there is mainly uniform national standards for shale gas concerns air pollution, which are governed by the US EPA.

6 Discussion and conclusion

The Bloomington School clarifies why it makes sense to let a thousand regulatory flowers bloom, rather than to establish uniform standards, to govern shale gas development. There are important benefits to a diversity of regulatory response to shale gas development the polycentric systems we considered, such as balancing the need for regulation with recognition of the diversity of preferences about economic development and generating knowledge about the appropriate (or inappropriate) ways to regulate an innovative technology. Moreover, the regulatory apparatus of the lower levels of government in each federation under consideration—the American states and the member countries, respectively—are capable of regulating shale production without further centralization of authority.

The most important justification for polycentrism may be in its epistemic functions. Regulatory experiments that work can be adapted. Those that fail can be avoided. This information constitutes a regulatory knowledge commons. The generation of knowledge through a trial and error process is challenging to quantify, but it is a powerful justification for self-governance of innovative technologies to extract minerals.

We conclude by noting the affinity between polycentric governance and liberal political economy. The defining features of liberal political economy include a deep appreciation for the dynamism of markets and recognition that government is neither omniscient nor omnipotent (Boettke 2017; Leeson and Subrick 2006). Polycentric governance is a political institution that recognizes the important of markets and spontaneous order, as well as the limitations of centralized government regulation economic activities. In many ways, it is the political institution of liberal political economy. Its epistemic and generative properties are especially important in identifying the best ways to regulate the process of economic development.

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