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COMBATING BUDGETARY COMPLICATIONS FROM THE MARCELLUS SHALE: THE CASE FOR A PENNSYLVANIA GAS FUND

A Thesis

Submitted to the McAnulty College and Graduate School of Liberal Arts

Duquesne University

In partial fulfillment of the requirements for
the degree of Master of Arts

By

Daniel R. Thompson, II

May 2013

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2013

COMBATING BUDGETARY COMPLICATIONS FROM THE MARCELLUS SHALE: THE CASE FOR A PENNSYLVANIA GAS FUND

By

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Approved February 22, 2013

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ABSTRACT

COMBATING BUDGETARY COMPLICATIONS FROM THE MARCELLUS SHALE: THE CASE FOR A PENNSYLVANIA GAS FUND

By

Daniel R. Thompson, II

May 2013

Thesis supervised by Kent Moors

The relationship between shale gas development and budgetary and microeconomic externalities was studied. The extraction activity in the Barnett shale formation provided a case study for assessing per-well highway infrastructure damage and water usage. The creation of a predictive model based upon the Barnett was applied to the Marcellus formation. The results showed support for the hypothesis that shale gas development creates negative externalities that amount to unfunded mandates and free-rider problems for states and localities. Implications and policy solutions, including the case for a Pennsylvania natural gas fund, are discussed.

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Foremost, I would like to take a moment to thank my wife, Rebecca Maclean. Without her love, patience, and her constant, superlative support and indomitable belief in my work and abilities, this research would have likely never seen the light of day.

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Arkansas Geological Survey	(AGS)
Barnett Shale Formation	(BSF)
Department of Environmental Conservation	(DEC)
District and County Statistics	(DISCOS)
Drilling-Adjusted Vehicle Numbers	(DAVN)
Gross Domestic Product	(GDP)
Liquid Natural Gas	(LNG)
Marcellus Shale Formation	(MSF)
National Conference of State Legislatures	(NCSL)
Natural Resource Fund	(NSF)
New York Mercantile Exchange	(NYMEX)
Pennsylvania Department of Environmental Protection	(DEP)
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Texas Department of Transportation	(TxDOT)
Texas Railroad Commission	(TRRC)
Texas Water Development Board	(TWDB)
Thousand Cubic Feet	(MCF)
Trillion Cubic Feet	(TCF)
West Texas Intermediate	(WTI)

Chapter 1: Introduction

Western Pennsylvania stands on the cusp of a growing wave of economic and energy development that will prove every bit as monumental and inescapable as the Spindletop strike. Pennsylvania rests at the epicenter of Marcellus shale gas development, arguably the largest unconventional natural gas reserve on the planet. As Pennsylvania quickly adjusts to the new realities of having the state of its economy dictated by the economics of resource extraction, the population will likewise need to understand, manage, and mitigate the negative side effects of this extraction economy. If the state government and policy makers do not prepare for these issues while Marcellus production is still in its infancy, they will find these problems particularly difficult to address in a reactive manner.

Many other states and nations have found themselves in a similar position – possessing substantial mineral wealth which, when extracted, created the environment that could potentially be impacted by price volatility, several types of inflation, and other economic problems. Some have elected to establish what have been referred to in oil and gas producing nations as oil funds, or more generally, natural resource funds (NRFs). Such funds act as fiscal policy tools to support long-term management of resource revenue. In Norway, for example, revenues from petroleum extraction are transferred into the fund and then invested abroad, "to avoid overheating the Norwegian economy and to shield it from the effects of oil price fluctuations…. The aim is to have a diversified investment mix that will give the highest possible risk-adjusted return within the guidelines set by the [Ministry of Finance]" ("Government Pension Fund Global").

Energy has always been a critical component of political and economic concerns, at all government levels. Concerns about energy factor directly or indirectly into almost all political or economic issues. With Pennsylvania's position over the bulk of the Marcellus shale formation, and the debate over the extraction of this energy source quickly heating up, research on this topic in real-time can be valuable both for the policy makers involved in the debate and the citizens of Pennsylvania.

Thus far, the debate over developing the Marcellus shale formation (MSF)[1] has been limited to a debate between the pro-development/pro-business lobby and the environmental lobby. Most people on both sides of the debate agree on many of the overall likely economic benefits.[2] However, the negative economic externalities have not been fully considered. Because of this oversight in addressing inflation and volatility, determining a way to deal with these issues has not been addressed. This thesis aims to address the development of negative economic externalities like the Dutch Disease, sectoral inflation, micro-inflation, and price volatility, as well as the destruction of non-related industries. This thesis will explore how these problems can be managed and mitigated effectively by the creation of a natural resource fund.

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[1] The Marcellus shale formation is a large underground shale deposit from which considerable amounts of natural gas will likely be extracted. More specific information about this is provided later in this work.

[2] Notable exceptions include people concerned about eco-tourism, particularly from the perspective of water quality. Particularly on more localized levels, the loss of eco-tourism commerce could be devastating (Delaware Riverkeeper).

Chapter 2: Review of the Relevant Literature

2.1 The Shift from Oil to Gas: Current Trends and Issues

Oil has been the dominant fuel for modern economic development for over a century. The metaphorical engine of oil development began to roar in earnest with the advent of the oil-fueled British Navy at the behest of the Admiral John Fischer. Since that point in the early 20th century, oil has been both the fulcrum and the nexus of world geopolitics, dominating warfare, finance, commerce, and industry like no other commodity or good has done before or since.

However, such dominance has come at a hefty price. The developed world is now completely dependent upon oil and oil-based products. The result is a dwindling supply both at home and abroad, despite ever-increasing demand. In fact, with the entrance of commercially- and industrially awakened China and India, there is simply not enough oil to keep up with the exploding demand of so many major consumers.

Enter natural gas. Long an alternative of oil, natural gas has nevertheless remained less than ideal for a number of reasons. However, the desirability of natural gas has increased as the price of oil has steadily increased, and will continue to do so. This increase in demand has driven, and will continue to drive, new development in exploration and production as time moves forward.

2.1.1 Declining Worldwide Oil Production

Many energy commentators, beginning with L. King Hubbard over 50 years ago, have predicted the coming of Peak Oil.[3] Tony Eriksen, a commentator on the Peak Oil phenomenon, estimates that the world has already reached peak production. According to him, "[w]orld production peaked in 2008 at 81.73 million barrels/day (mbd)."[4]

While few deny the existence of Peak Oil,[5] opinions vary as to the real importance of it and the gravity of the situation. However, the Peak Oil debate illustrates the tangible pressure within the market to move away from oil as the primary fuel for the United States' economy, whether due to the reality of Peak Oil as a real problem or as part of the natural innovation process away from oil as a primary fuel. While it remains unlikely that such a shift will occur abruptly, this increasing pressure will prompt more

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[3] Peak oil is a concept that originated with the now-deceased M. King Hubbert, an American geophysicist who worked for Shell Oil Company. His aggregate production/depletion curve, known commonly as the Hubbert curve, was based on the now widely accepted premise that world oil supply is finite. With it, he correctly predicted peak production in the United States.

[4] Eriksen continues in his discussion of world peak oil: "This oil definition includes crude oil, lease condensate, oil sands and natural gas plant liquids. If natural gas plant liquids are excluded, then the production peak remains in 2008 but at 73.79 mbd. However, if oil sands are also excluded then crude oil and lease condensate production peaked in 2005 at 72.75 mbd…. Non-OPEC oil production peaked in 2004 and is forecast to decline at a faster rate in 2009 and beyond due mainly to big declines from Russia, Norway, the UK and Mexico. OPEC has the ability to increase production later this year and in early 2010. Although key OPEC producer Saudi Arabia peaked in 2005, it probably has sustainable annual surplus capacity of 1mbd. Iraq and possibly Nigeria also have potential to increase production but these countries continue to have serious internal conflicts. By the time 2011 arrives, OPEC will not have the ability to offset cumulative non-OPEC declines and world oil production is forecast to stay below its 2008 peak" (Eriksen).

[5] The primary exception to this acceptance of the existence of peak oil resides in the debate over the existence of abiotic, or abiogenic, oil production. This theory, originally German in origin, gained considerable renown in Russia, particularly under the Soviet Union, as a result of writings by Dmitri Mendeleev and a number of subsequent Soviet geologists. The theory has generally fallen out of favor, particularly in the West, due to the theory's inability to predict locations of new oil deposits.

development in natural gas production worldwide. This can already be witnessed in China, as the country has recently begun preliminary planning and development of its own shale gas resources ("China"), in partnership with American companies and the US government ("US-China"). The resulting shift will likely cause increased pressure and price volatility in natural gas prices due to newer and potentially cheaper-to-develop gas deposits coming online. This translates to greater budgetary and economic pressures elsewhere, particularly in places that rely heavily on royalties or revenues from natural gas extraction.

2.1.2 Unconventional Natural Gas Boom in the United States

The gas industry has taken a keen interest in shale gas formations for a number of reasons. The advent of directional drilling (also known as horizontal drilling)[6] and hydraulic fracturing (more commonly referred to as hydro-fracking, or fracking) have made natural gas extraction from shale rock formations economically viable. As a result, costs of extracting the natural gas have plummeted relative to other unconventional natural gas plays[7] like tight gas, coal-bed methane, and undersea methane hydrate deposits.

The second development relates to the price of natural gas. As it has risen over the past few years (despite its recent hovering in the mid-single digits in

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[6] Directional drilling "involves steering a downhole drill bit in a direction other than vertical. An initially vertical drillhole is slowly turned 90 degrees to penetrate long horizontal distances, sometimes over a mile, through… bedrock. Hydraulic fractures are then created into the rock at intervals from the horizontal section of the borehole, allowing a substantial number of high-permeability pathways to contact a large volume of rock" (Soeder and Kappel "Updated").

[7] A play is defined as either "the extent of a petroleum-bearing formation" or "the activities associated with petroleum development in an area" ("Natural Gas Play Definition"); though it is used in both oil and gas industries.

dollar terms per contract), the overall financial viability and profitability of unconventional gas development has increased. Because the wellhead prices of gas have risen “from values of less than $2.00 per MCF (thousand cubic feet) in the 1980s to a peak of $10.82 per MCF in the summer of 2008” (“EIA – Natural Gas Pipeline Network”), it is now financially feasible to expect a return on the capital investment needed for unconventional gas development. Even with the decline in prices due to the 2009 economic downturn, they are still substantially higher than a decade earlier (Soeder and Kappel “Water Resources”).

The energy market in the United States has already witnessed substantial unconventional gas development in both shale gas (the Barnett and Haynesville plays are the most mature[8]) and coal bed methane (the Powder River Basin[9] is by far the largest in the United States) relative to the rest of the world. This trend simply reflects the overall international trends, as the popularity of unconventional gas development increases, particularly in Europe and China.

2.1.3 United States as Net Natural Gas Exporter

Until recently, the Canadian natural gas industry, as well as the natural gas industry at large, had been gearing up for the projected increase in the importation of natural gas into the United States. Most observers had been predicting a gradual but sustained move away from oil and toward natural gas for many uses in the U.S., along with steady but substantial increases in demand of natural gas as a bridging fuel that such a shift would likely entail. These projections were due in large part to the

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[8] The Barnett shale formation is located in north-central Texas and the Haynesville shale formation in northwest Louisiana/east Texas. More information about both formations is discussed later on in this section.

[9] The Powder River Basin is located in southeast Montana and northeast Wyoming.

acknowledgement that the U.S. conventional natural gas production had already peaked as of 2001 (Gilardoni), as well as a dearth of economically viable replacement supply to make up the difference.

For the foreseeable future, natural gas will be a key energy source for the developed and developing world. This is already the case for Europe. According to one source, between 60% and 90% Europe's natural needs must be imported from non-European nations, particularly Russia. Unlike Europe, which has considerably fewer and poorer sources of conventional natural gas, as well as smaller and less-developed unconventional natural gas plays, the US could conceivably become a net exporter of natural gas.

To that point, the Kitimat Liquid Natural Gas (LNG) facility had originally been tasked as an import point for LNG into North America – particularly for markets in the U.S. However, since that time technology has progressed to the point that "[t]he Department of Energy now predicts that shale gas could meet half America's demand within two decades and turn the country into a net exporter" (Fortson). As a result, Kitimat is being refitted as an export facility (Vanderklippe). This new development, something as simple as re-tasking a LNG facility from importing to exporting, signals a sea change in the future of North American natural gas production, and the world natural gas market as a whole.

The potential for continued linkage between oil and gas should be of grave concern for any policymaker basing his or her budgetary projections upon proceeds related to the market price of natural gas.

2.1.4 The Role of Natural Gas in Future United States' Energy Needs

Oil has clearly dominated the energy markets of the world for decades. Indeed, oil will likely continue to do so for much of the foreseeable future. However, that dominance of the world energy markets will be for slightly different reasons moving forward than it has been in the past. Until now, oil has dominated the world energy markets as a direct result of how plentiful, fungible, transportable, and relatively cheap it has remained for decades. However, oil's destructive effect on the energy markets will be a direct result of oil having become the hydrocarbon of choice the world over (Moors). Due to oil's ubiquity in both energy uses (particularly transportation and industrial uses) and as a financial commodity in its own right, the price of oil has become considerably more difficult to predict. Such price volatility will necessitate consumers, where possible, to change to other, more stably-priced hydrocarbon products, especially for transportation uses. Despite oil's hitherto relative price-inelasticity[10] in the transportation market, there have been signs that such price-inelasticity has rather defined limits, and that those limits will be reached in the near future.[11] Moreover, this view has become more common as time has gone on, leading many to call for more reliable (and more domestic) supplies of energy. Dr. Timothy Considine, former professor at the Pennsylvania State University and now professor at University of Wyoming, states that "[n]atural gas is widely viewed as a bridge between the age of oil and the next energy paradigm, perhaps based upon

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[10] Price elasticity of demand refers to the responsiveness of aggregate demand to changes in price when all other factors are held constant.

[11] This was witnessed when gasoline prices reached $4-$5/gallon in 2008. The effect of this price point seemed to carry a "psychological effect" that numerous economists and observers noted at the time. As prices approach, and in some areas surpass this price point again, some predict a similar chilling effect on the overall economy again. The debate is still open as to whether this will occur or not (Gelsi).

some combination of nuclear, solar, wind, and biomass resources…. By developing domestic natural gas resources here in the United States, greater energy import dependency and higher trade deficits could be avoided. Liquid fuel imports also could be displaced if these new natural gas resources could be utilized in transportation" (Considine et al. "An Emerging Giant" 2).

2.1.5 Positive Effects of Natural Resource Development

According to the 2009 Considine report, "An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play," Pennsylvania has already begun to experience benefits that are merely the beginning of greater improvements on the horizon. Considine noted that Pennsylvanians should expect substantial increases in employment across numerous sectors of the economy, as well as substantial increases in net tax inflows. Considering the hemorrhaging of jobs that Pennsylvania has experienced since most of its heavy industry left several decades ago (steel, iron, coke, etc.), development of the MSF is seen as a panacea to local and state policymakers. Both the remittance of funds generated by the pending severance tax on gas extraction and the increase in industry, commerce, and employment due to the MSF development will vastly improve Pennsylvania's economy.

The basis of the state's optimistic outlook with respect to the Marcellus – centered on economic benefits, taxes and jobs – correctly indicate a critical piece of understanding regarding shale development. While some benefits will be felt primarily on the local level, particularly the increase in employment, the overall benefits will tend to more generally apply themselves throughout the state. Philadelphia, for example, will undoubtedly enjoy many of the positive externalities[12] of the MSF development despite having no shale beneath it and as a result remaining relatively unscathed by the local problems with development.[13]

The 2009 Considine report, as well as the subsequent report published in 2010, are supportive of MSF development and its benefits to Pennsylvania and urge caution with potentially short-sighted taxation or regulation. According to Considine, natural gas development is a highly competitive industry that is extremely vulnerable to natural gas volatility. This has been seen in the Barnett, particularly from 2008 onward, when new well-drilling activity peaked. Considine's report recommended that Pennsylvania should minimize both taxation and regulation so as to maximize economic activity stemming from Marcellus development. That report contends that a "larger industry in the long run will be a far greater generator of government tax revenues than an industry stunted by high taxes or costly regulations" (Considine et al. "An Emerging Giant" 3). While these authors are promoting an extremely industry-friendly environment, a long-term view is needed so as to not have companies dictate terms to governments or the general population. The aim of economic policy from the standpoint of a state (or national) government should focus on sustainable

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[12] Some of these positive externalities may be in the form of potentially lower natural gas prices and greater business activity resulting from those lower prices. The potentially lower prices will be the result of proximity to supply, as well as being part of the northeast U.S. corridor. Most of the natural gas from Marcellus development will likely be piped east to fulfill demand from New York City to Washington, D.C.

[13] It should be noted that while Philadelphia will likely be *relatively* negatively affected by shale gas development, this should not imply that the eastern reaches of the state will be *completely* unscathed. Refer to the discussion of watershed and eco-tourism later in the work.

growth, rather than promoting the type of boom and-bust cycles that tend to eviscerate the economic viability of other industries at the expense of an extractive one. Considine's point above makes it clear that such negative attendant effects rarely receive any attention. From the extant literature, few researchers have addressed the possibility that a state within a larger nation might not benefit from extractive industry.

There are a number of reasons why the positive economic effects of development are generally addressed more often by researchers. One of the biggest reasons is that positive economic factors of MSF development tend to be easier to study. There tends to be a considerable amount of data available for such research. One example can be found in the following quotation from the 2009 Considine report:

> A more meaningful estimate of economic impacts is value added, which subtracts inter-industry purchases from gross output and measures the returns to labor and capital. Using this measure, the Marcellus gas industry in Pennsylvania directly added $1.1 billion to the economy of Pennsylvania, which then generated indirect and induced impacts that increased the total value added generated in the Commonwealth by $2.3 billion. In other words, the total economic impact of the Marcellus industry measured by valued added was $2.3 billion during calendar year 2008 (Considine et al. "An Emerging Giant" 24).

Without doubt, the development of the MSF will create many economic winners, as has already been witnessed in places like Washington and Bradford counties,[14] where the bulk of development in Pennsylvania has occurred thus far.

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[14] Washington and Bradford Counties have been the early epicenters of Marcellus shale development, particularly in Pennsylvania. Washington County is located southwest of Pittsburgh, on the border with West Virginia. The county seat of Washington County, Washington, PA, is approximately equidistant between Pittsburgh, PA and Wheeling, WV ("Washington County"). Bradford County is located along the northern border of Pennsylvania with New York State. Its county seat is Towanda, PA, which is located almost due south of Sayre, PA ("Welcome to Bradford County").

Many of the so-called “winners” of Marcellus shale development have been farmers and landowners, many of whom have struggled for decades to simply tread financial water to avoid insolvency and bank repossession of their farmlands. Through royalty payments and leasing proceeds, many of these people have managed to turn tidy profits and become relatively well-off, particularly when compared to their neighbors. Thanks to the experiences of these landowners, as well as published studies both by academia (Considine’s work exemplifies this) and industry in general,[15] the case for developing MSF quickly has been made very strongly. Little attention has been paid to the likely negative economic externalities associated with MSF development.

2.1.6 The Negative Effects of Development

As natural gas is extracted from the MSF, the state of Pennsylvania will begin to become more and more dependent upon revenue and economic activity directly resulting from resource extraction. Table 1 addresses these issues.

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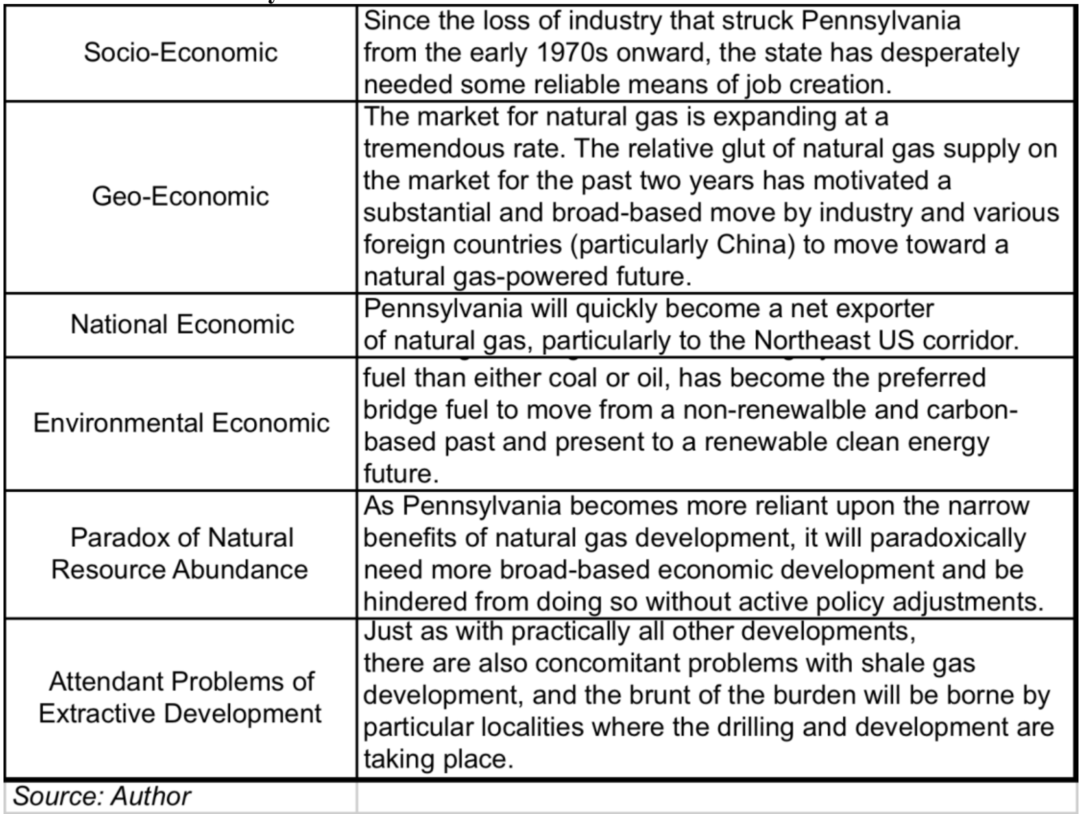
[15] Range Resources, in particular, has been at the forefront of putting a positive spin on the Marcellus development. This has been aided greatly by the efforts of the Marcellus Shale Coalition, essentially an industry front-group that has effectively lobbied to both maximize shale gas development as well as minimizing regulation and taxation. More information can be found on their website (“Marcellus Shale Coalition”) as well as an opposing website (“Marcellus Shale Coalition – Source Watch”).

Table 1. Potential Policy Issues Related to Resource Extraction



Socio-Economic	Since the loss of industry that struck Pennsylvania from the early 1970s onward, the state has desperately needed some reliable means of job creation.
Geo-Economic	The market for natural gas is expanding at a tremendous rate. The relative glut of natural gas supply on the market for the past two years has motivated a substantial and broad-based move by industry and various foreign countries (particularly China) to move toward a natural gas-powered future.
National Economic	Pennsylvania will quickly become a net exporter of natural gas, particularly to the Northeast US corridor.
Environmental Economic	fuel than either coal or oil, has become the preferred bridge fuel to move from a non-renewalble and carbon-based past and present to a renewable clean energy future.
Paradox of Natural Resource Abundance	As Pennsylvania becomes more reliant upon the narrow benefits of natural gas development, it will paradoxically need more broad-based economic development and be hindered from doing so without active policy adjustments.
Attendant Problems of Extractive Development	Just as with practically all other developments, there are also concomitant problems with shale gas development, and the brunt of the burden will be borne by particular localities where the drilling and development are taking place.
Source: Author	

Few if any of the above problems solely affect a single subject. Oftentimes, these effects can be difficult to unpack or disentangle from one another, as they may present sympathetic or mutually enabling problems or synergistic relationships that worsen the overall negative effects. Indeed, only by addressing them all at once can policymakers hope to truly and effectively mitigate the negative attendant effects of natural resource extraction.

2.1.6.1 Negative Environmental Externalities

Hydrocarbon development of all types inexorably leads to water pollution. The flowback water[16] from the shale gas drilling will potentially contain a number of potential

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[16] "*Flowback water* (aka *backflow water*) is the murky, salty water from fracking natural gas wells. It consists of frac fluid which returns to the surface (aka the *frac load recovery*) as well as produced water. This water contains clay, dirt, metals, chemicals and even diesel that may have been added" ("Flowback water").

pollutants, including but not limited to salts, sand, acids (hydrochloric, sulfuric), bromides, thorium, uranium, radium, sulfides, pyrite, chlorides, zinc, chromium, molybdenum, cobalt, arsenic, vanadium, nickel, chromium, barium, calcium, iron, magnesium, manganese, and strontium, and calcium carbonate ($CaCO_3$).[17] Any of these substances can prove to be deadly in their own right. The Dunkard Creek fish kill of 2009[18], for example, demonstrates the potential for a single moderate to large spill to impact the environment. However, the state Department of Environmental Protection (DEP) can, in theory, mitigate this damage.

Generally, well-site spillage has traditionally represented the greatest source of water pollution in shale gas drilling. However, the state has already begun to take regulatory and oversight action to curb spillage pollution. In this way, DEP is currently addressing the largest and most obvious point sources of groundwater pollution.[19] However, this leaves another source of environmental pollution unaddressed.

The long-term effects of fracking remain a bit of a mystery, even to geo-physicists and geologists. No one is completely sure what a frack actually does, short of creating

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[17] The Democratic members of the Committee on Energy and Commerce recently released a report that identifies many of the chemicals found in fracwater ("Chemicals").

[18] Dunkard Creek, which straddles the Pennsylvania/West Virginia border, experienced a massive fish kill in September 2009 along thirty miles of its length. Golden algae bloomed in the creek as a result of "low, warm creek flows and high levels of chlorides and dissolved solids…[which] were high because of discharges from a mine treatment facility at Consol Energy's Blacksville No. 2 deep mine and a second treatment facility at Consol's Loveridge deep mine near the West Virginia town of St. Leo. Another contributing cause… could be what [was] described as a discharge from a new borehole into which an unspecified company is injecting drilling wastewater into a mine void" (Hopey).

[19] One of the major environmental issues that should be addressed more directly is the interstate/cross-border effect of shale gas development. This is a particularly salient issue in light of New York State's moratorium on new shale gas development, and West Virginia's and Ohio's relative lack of development when compared to the development in Pennsylvania.

micro-fissures within the underlying shale formation, thereby releasing the captured gas. The development of fracking technology and the use of this technique in the field have led to numerous problems, such as micro-earthquakes[20], destruction and adulteration of underground aquifers and groundwater, and water pollution in the form of flowback water and spillage. Even without these specific problems, the development is considered heavy industry, and there is generally a localized resultant destruction and degradation of transportation infrastructure and noise pollution, as well as a considerably greater volume of traffic. All of these issues either directly or indirectly affect the localities where the development occurs. Then there are the economic problems, which can lead to such issues as an overall loss of jobs (mostly in completely unrelated sectors), skilled labor shortages, and slower overall economic growth.[21]

2.1.6.2 Infrastructure Degradation

The development of practically any extractive industry dramatically increases the load that local infrastructure must bear. Shale gas development is not an exception. The equipment necessary to drill and frack the formation, water transport trucks for the initial fracking process, and the trucks necessary for subsequent disposal of the effluent water must make seemingly countless trips at each drilling location. This greatly increased traffic leads directly to accelerated road degradation. It does so rather quickly because

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[20] Hydrofrack-induced micro-earthquakes have been noted since at least as far back as 1982 (Keppler et al.). More recent anecdotal evidence (“Fracking”) refers to considerably more frequent micro-quakes. Another, more official, record can be found at a site maintained by the Arkansas Geological Survey (AGS) (“Earthquakes”).

[21] The problems mentioned here generally are considered to be associated with Dutch disease/resource curse phenomena. These issues are discussed in greater detail later in this work.

most drills are located in rural areas and those local roads were not generally designed to service heavy industry traffic.[22]

2.1.6.3 Commodity Price Volatility

When nations or states base their budgets upon the vagaries of the commodities markets, the result is generally rather predictable. As Tsalik and Ebel tersely point out, "Price volatility makes budget planning difficult" (Tsalik and Ebel 5). When a government expands services based on expanded revenues from higher commodity prices, the budget rarely takes into account the inevitable revenue decline. The result generally leads to a subsequent elimination or curtailing of the originally expanded service (ibid). This can lead to all manner of political and economic difficulties.

Between the volatility of the actual price of natural gas and competition from both domestic and foreign sources of natural gas, governments in natural gas producing areas will come under dramatic pressures with which the policymakers there have little, if any, experience.

2.1.6.4 Resource curse/Dutch Disease

Another troublesome problem that resource-extraction-dependent states and nations suffer has become known by a number of monikers, some referring to the entire problem, and others referring to a small portion thereof. While contemporary scholarship identifies both 'resource curse' and 'Dutch Disease' as slightly different manifestations of the same problem, the two terms can be used interchangeably in most cases.

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[22] This phenomenon will be discussed in considerably greater detail later in the work. Two locally maintained websites address this problem specifically ("Chesapeake," "Road Damage").

The Dutch Disease has been studied at considerable lengths in recent years. The term Dutch Disease refers to a phenomenon first observed in Holland that resulted from the discovery of natural gas in the 1960s (Tsalik and Ebel 5-6). The Dutch Disease occurs as a direct result of the development of extractive industries, which tends create inflows of hard currency into the economy in question as the natural resources flow outward. This hard currency influx tends to stimulate various problems related to foreign exchange rates, particularly as this hard currency is converted into the local currency, essentially raising the value of that domestic currency. This inflationary effect tends to increase the real cost of producing tradable goods, resulting in less competitive pricing vis-à-vis cheaper foreign goods. This affects both the domestic and foreign markets. As sales decline in the home economy, labor-intensive, mature industries and economic sectors tend to decline, leading to unemployment and increased dependence upon natural resource development. This can have highly destructive effects upon both the domestic economy as well as upon the public sector, particularly governments highly dependent upon tax revenue for service provision.

While this explanation of the phenomenon seems to focus mostly upon nation-states, the mechanism remains the same for smaller administrative units within nations, such as American states. For areas that have been extremely hard-hit in the past by deindustrialization, this economic phenomenon must be taken very seriously. As Tsalik and Ebel point out, a great many studies have determined that relatively resource-poor countries tend to have stronger growth in Gross Domestic Product (GDP) per capita than countries blessed with natural resource abundance. They go on to note that this disparity in GDP growth per capita actually tends to increase as the price of the commodity in question increases.[23]

Perhaps most important in Tsalik and Ebel's work is their recognition that suffering from the Dutch Disease does not necessarily represent a foregone conclusion for resource-extractive economies. "Countries like Botswana, Indonesia, and Malaysia have managed to improve development while diversifying their economies from excessive reliance on natural resources (Tsalik and Ebel 7). NRFs seem to be a viable policy option for the negative effects of resource extraction-based economies.

Until now, research on the Dutch Disease has been limited to considering its effects upon entire nations, particularly developing nations.[24] While some have also considered developed nations, particularly Norway, none consider the potential effects of the Dutch Disease on political or administrative subdivisions within a nation-state, whose economies rely heavily on resource extraction. Part of the aim of this work will be to address that issue directly.

One of the main reasons Dutch Disease research has been limited to considering only nation-states is due in part to the fact that the Dutch Disease is thought to be primarily an affliction stemming largely from hard currency-related inflation. The US economy in particular is also thought to be large enough to stave off the effects of the Dutch Disease by absorbing the potential for currency devaluation and smoothing the negative effects for individual states. While both statements are true, there are some

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[23] Tsalik and Ebel specifically discuss oil in this particular situation, noting that between 1960 and 1990, countries with comparatively little oil wealth tended to grow at rates ranging from double to triple rates experienced by comparatively oil-rich nations (Tsalik and Ebel 3).

[24] Norway, Russia, Azerbaijan, Nigeria, Botswana, and Brazil, among others, are primary subjects of study (Wright and Czelusta).

problems with this perspective. First, currency devaluation is only one characteristic of the Dutch Disease. Indeed, once could argue that the sectoral and localized inflation generally experienced in conjunction with the Dutch Disease always exists in some capacity in resource-extraction-dependent economies. Certain political or financial realities specific to each individual economy serves to exacerbate or mitigate the effects. In this way, the states in the US that base a large portion of their economies of resource extraction benefit from being part of a large, diversified economy. However, while the economy of the nation may be diversified, the local and regional economies tend to be less so. The so-called "Rust Belt" cities are a case in point. Despite the fact that many of these areas were areas of high industrialization, the fact of the matter remains that these areas tended to be, nonetheless, rather one-dimensional and almost as vulnerable to these Dutch Disease effects as regions that rely solely on extractive development. The degree to which a given economy is dependent upon an industry – extractive or otherwise – determines to a great degree how strong a case of the Dutch Disease that economy could "catch."

The existence of a legitimate, democratic political system likewise lessens the difficulties related to corruption most nations, particularly developing nations, tend to experience. Overall, countries with good institutions are more likely to benefit from the economic blessing and less likely to suffer from the political curse (Cotet and Tsui). While Cotet and Tsui are correct on this point, they challenge the existence and power of the Dutch Disease by treating entire countries as uniform entities without regional differences that could their positions. While the resource curse assumes the existence of a resource is an economic blessing (Cotet and Tsui 491), this presumption should be conditionalized. While the resource represents substantial wealth, the questions of how those resources, the rents, and royalties are allocated, as well as how quickly those resources are developed and extracted must also be addressed. In this way, in addition to being an economic boon, natural resources can likewise be an economic curse.

2.1.6.5 Micro-Inflation/ Sectoral Inflation

Just as resource extraction industries can have substantially negative effects on macro-level economic issues in a given economy, such industries can also negatively affect micro-level concerns. Of particular concern are micro-inflation and sectoral inflation, two sides to a common problem.

Just as inflation is a result of increased economic activity (oftentimes seen in economies in which there have been substantial injections of currency, or when the velocity of money increases, or both), micro-inflation is the phenomenon of increased economic activity on the very local level. While rarely a concern for most economists, micro-inflation can create public policy complications with profound long-term outcomes.

Housing rents, for example, tend to be one of the most sensitive indicators of micro-inflation resulting from faster economic development. When more work has been created – when a given natural resource begins to be developed – new workers are often needed in order to provide the requisite labor force necessary to successfully develop the play. This need for additional manpower often necessitates the importation of outside labor, particularly for the types of highly specialized jobs required for such industries as natural gas development. These new workers require shelter, and oftentimes the employers of these workers are willing to pay a premium for such housing. This additional demand created by the new non-indigenous labor, as well as the premium that may well be paid for housing, has the effect of driving prices up, putting the squeeze on local citizens. If the overall wages and income remain stagnant or growth trails behind the increases in costs for housing, the end result can be tremendous pressure upon the indigenous population.[25]

This mechanism functions with particular power on necessities, such as food, water, shelter, clothing, etc., that have traditionally high price inelasticity. The net public policy result if these issues are not addressed will likely be angry or beleaguered citizens.

The flip-side to micro-inflation is sectoral inflation. Sectoral inflation is an economic phenomenon that occurs when development in a particular sector of the economy forces the prices of goods upward. Sectoral inflation essentially manifests as a location non-specific supply-side version of micro-inflation. The mechanism looks very similar, but the results can be even more detrimental to an economy, as the effects tend to be more persistent and more difficult to rectify after the fact.

Specialized labor shortages represent a good general example of sectoral inflation. When specialized labor becomes necessary for a new and fast-growing industry to succeed, the new demand places upward pressure on the local (or even regional) labor costs, putting pressure upon more mature industries with considerably more stable and relatively fixed profit margins. By forcing the cost of labor inputs upward, it becomes more difficult for those mature industries and firms to retain the necessary specialized labor without trying to compete for those laborers. The net result can easily be the

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[25] Because of the nature of such short time horizon boom/bust cycles, public policy responses tend to be muted or nonexistent. This lack of response can create or exacerbate additional pressures and social impacts upon localities and their citizens, particularly on low-income or homeless people.

contraction of these more mature industries, leading to a general de-industrialization or de-commercialization of the affected area.[26]

While labor certainly represents the most visible example of sectoral inflation, it certainly does not hold a monopoly on being affected by it. Practically any input for supply at any point within the supply chain can fall victim to sectoral inflation. The more similar the skills or inputs of the resource extractive industry to other industries, the more severe the effects on the more mature industry will be.

Indeed, there already exists ample reason for concern about the above inflation-based issues. “Expenditures at all stages of production generate indirect economic impacts as the initial stimulus from expenditures on natural gas development is spent and re-spent in other business sectors of the economy” (Considine et al. *The Economic Impacts* 18). Considine admits that there will be substantial impacts on the economy, locally, regionally, and nationally. However, he fails to acknowledge the potential harm these impacts will have upon the economy, either at the macro- or the micro- levels:

> [T]he construction of supporting infrastructure is a very significant undertaking that requires thousands of suppliers of steel, machines, and equipment. These suppliers would have to ramp-up to meet this new demand by hiring thousands of workers, often in relatively high paying manufacturing and construction jobs. Pennsylvania experienced such an industrial boom during the last half of the 19th century, leaving behind vast wealth that underpins great institutions, such as Carnegie Mellon University, which generate benefits for citizens today (Considine et al. “An Emerging Giant” 6).

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[26] Richter’s article in Foreign Affairs discusses the Fed’s role in tamping down inflation concerns as well as the effect immigration tends to have in assisting in such policy concerns. It should be noted that labor inflation has been a chief concern informing Federal Reserve policy dating back to Volcker’s term, and particularly under the chairmanship of Alan Greenspan (Richter).

While the actual net effects of this development remain unclear at present, the overall net result will likely fall well short of the panacea that many boosters of shale gas development.

Similarly, as the demand for steel pipe increases with the continuing development of the MSF, the price for steel pipe (and steel as well) will rise, affecting other sectors of the economy. This type of inflation can have dramatic and negative effects upon other industries within an economy, depressing overall economic activity despite the increase in economic activity in the sector that initially created the sectoral inflation. Not only could sectoral inflation exacerbate a recession if it occurs during one, it could potentially be the root cause of a recession, particularly on a local or regional level. Considine makes a point to establish the level of economic growth that would result in the development of the MSF.

> The Marcellus industry purchases of goods and services, their royalties to landowners, and tax payments directly create more than 14,000 jobs in Pennsylvania. Indirect and induced impacts create even more jobs so that total jobs created by the Marcellus industry is estimated at 29,284…. The results of this study indicate that for every $1 million of output created by natural gas in the Pennsylvania Marcellus, 6.9 jobs are created (Considine et al. “An Emerging Giant” 25).

Such a dramatic expansion in one particular sector of the economy could easily produce negative side effects for numerous other industries.

2.1.7 Mitigating Negative Externalities

Policymakers tend to fall into two categories in response to negative externalities. On the one hand are the laissez-faire policymakers who tend to put considerable faith in the power of the market to mitigate or rectify market failures or pressures that will affect citizens. On the other hand, some policymakers take a more active approach, concerning themselves with the immediate welfare of citizens. For those policymakers who tend to take a more active role, there exist a number of policy responses. Two of the most popular, and most effective, are severance taxes and NRFs.

2.1.7.1 Severance Tax

Severance taxes[27] provide the opportunity to mitigate issues that may arise as a result of natural resource extraction. Thirty-five states in the US have already instituted some form of resource extraction severance tax,[28] as well as many nations.[29] These taxes can be as general or specific as the imposing government chooses, both from the standpoint of how specifically the tax can be assessed and how the proceeds of the tax is spent. For the most part, states that have severance taxes on extractive industries choose to funnel most of those royalties into their general fund. West Virginia and Alaska are notable exceptions.[30] Much of that state's severance tax revenue gets spent on environmental remediation efforts for coal-related environmental destruction. The

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[27] Severance taxes are defined as "a tax levied by a state on the extractor of oil, gas, or minerals intended for consumption in other states" ("Severance tax").

[28] A list of U.S. states that have adopted severance taxes is included later in this work.

[29] Nations that have instituted natural resource funds tend to use some form of severance tax to provide revenue for their NRFs.

[30] Fifteen U.S. states remit a portion of severance royalties back to localities. Those states include the following: Colorado, Florida, Kansas, Kentucky, Louisiana, Mississippi, Montana, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Tennessee, West Virginia, and Wyoming. Ten states set aside, as a matter of law, a percentage of the severance taxes collected for environmental remediation and for additional conservation efforts. These states include the following: California, Colorado, Florida, Louisiana, Montana, New Mexico, Ohio, Oklahoma, West Virginia, and Wyoming. Most states choose to fund these allocations as expenditures in the general fund, making them subject to the normal political process, whereas a small handful (Alaska, New Mexico, and Wyoming) use a separate fund, much like numerous nation-states have chosen to do. This policy option serves essentially to insulate the funding of those policies from many, if not all, political conflicts. Alaska also uses the proceeds of its severance taxes to both fund its NRF as well as provide what amounts to a pension to every citizen of the state. West Virginia employs a large portion of their collected severance proceeds for a number of uses, including environmental remediation ("Shared Costs").

following three tables illustrate how complicated the process of comparison can be when considering the severance tax regimes of various states. States use a variety of different calculation methods. This obviously does not lend itself easily to comparison. Table 2 provides a list of all states with current severance taxes, the amount of revenue those severance taxes provide to their respective states, and the percentage of the total state revenue the respective severance taxes make up. Table 3 shows the specific severance tax structures for the top 15 state natural gas producers in the US. Table 4 lists states with any sort of natural resource severance taxes and the resources upon which those taxes are levied.

Table 2. State Severance Tax Collections by State (thousands of dollars)[31]

	2010 total				2010 total		
	Total State Taxes Collected	Severance Taxes	Severance Taxes as % of total		Total State Taxes Collected	Severance Taxes	Severance Taxes as % of total
U.S. Total*	714,753,551	11,306,271	1.6%	Montana	2,222,043	272,772	12.3%
Alabama	8,307,027	96,538	1.2%	Nebraska	3,760,104	285	0.0%
Alaska	3,951,201	2,595,766	65.7%	Nevada	5,930,673	202,945	3.4%
Arizona	11,028,993	16,368	0.1%	New Hampshire	2,211,906	-	0.0%
Arkansas	7,443,887	76,170	1.0%	New Jersey	26,825,435	-	0.0%
California	112,406,085	27,104	0.0%	New Mexico	4,514,997	673,592	14.9%
Colorado	8,516,873	95,611	1.1%	New York	61,055,684	-	0.0%
Connecticut	12,593,716	-	-	North Carolina	21,656,598	1,534	0.0%
Delaware	3,652,978	-	-	North Dakota	3,061,360	1,404,120	45.9%
Florida	31,832,070	64,580	0.2%	Ohio	23,700,808	10,871	0.0%
Georgia	15,245,089	-	-	Oklahoma	7,275,795	800,262	11.0%
Hawaii	4,802,825	-	-	Oregon	7,552,522	19,287	0.3%
Idaho	3,031,089	7,639	0.3%	Pennsylvania	31,313,195	-	0.0%
Illinois	26,303,688	-	-	Rhode Island	2,636,424	-	0.0%
Indiana	13,997,781	-	-	South Carolina	6,957,823	-	0.0%
Iowa	6,506,865	-	-	South Dakota	1,311,209	10,076	0.8%
Kansas	6,681,079	115,550	1.7%	Tennessee	10,734,591	2,417	0.0%
Kentucky	9,844,695	333,519	3.4%	Texas	39,057,656	2,071,690	5.3%
Louisiana	8,016,733	754,404	9.4%	Utah	5,244,727	103,941	2.0%
Maine	3,562,520	-	-	Vermont	2,553,777	-	0.0%
Maryland	14,898,918	-	-	Virginia	16,317,268	1,927	0.0%
Massachusetts	20,775,614	-	-	Washington	16,564,300	24,082	0.1%
Michigan	22,504,603	56,548	0.3%	West Virginia	4,868,392	422,779	8.7%
Minnesota	18,094,858	15,719	0.1%	Wisconsin	14,923,258	4,955	0.0%
Mississippi	6,439,892	95,638	1.5%	Wyoming	2,141,011	927,581	43.3%
Missouri	9,922,916	1	0.0%	Washington, D.C.	5,037,561	-	0.0%

Source: US Bureau of the Census

* excludes Washington, D.C.

Note: X = No such tax for that state

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[31] Total taxes include: property tax, general sales and gross receipts, motor fuel sales taxes, alcoholic beverages, public utilities, insurance, tobacco products, pari-mutuels, amusements, other selective sales and gross receipts, alcoholic beverages, public utilities, motor vehicles, motor vehicle operator, corporations in general, hunting and fishing licenses, occupation and business licenses, other licenses taxes, individual income taxes, corporation net income taxes, death and gift taxes, severance taxes, documentary and stock transfer taxes, and other miscellaneous taxes.

Table 3. Severance Tax Rates and Corporate Taxes in the Top 15 Natural Gas Producing States

Rank	State	Annual Production (MCF)	Severance Tax Calculation	Type of Corporate Tax
1	Texas	6,091,724	7.5% of market value of gas produced	Franchise Tax*
2	Wyoming	1,923,224	6% of taxable value (gross sales minus certain processing and transportation costs)	No
3	Oklahoma	1,744,393	7% of average monthly price of gas plus 0.095% excise tax	Income Tax
4	New Mexico	1,544,830	8.67-9.5% depending on county and school district	Income Tax
5	Louisiana	1,363,538	$0.269 per MCF	Income Tax
6	Colorado	1,242,571	2% to 5% based on gross income	Income Tax*
7	Alaska	433,485	25% to 50% of net income	Income Tax*
8	Utah	376,409	5% when gas over $1.50 MCF	Income Tax*
9	Kansas	365,877	4.33%	Income Tax*
10	California	307,160	Conservation fee of $0.0079076 per MCF	Income Tax*
11	Alabama	270,407	0.08	Income Tax
12	Arkansas	269,886	0.05	Income Tax
13	Michigan	264,907	5.75%	Income Tax*
14	West Virginia	231,184	5% + $0.047 per MCF	Income Tax*
15	Pennsylvania	182,277	None	Income Tax

Source: Pennsylvania Budget and Policy Center

* - indicates that the state uses combined reporting for corporate taxation.

Table 4. States with Severance Taxes

Alabama	**Alaska**	**Arizona**	**Arkansas**	**California**
Coal and lignite severance tax Coal severance tax Forest products severance tax Iron ore mining tax Local taxes Oil and gas conservation and production tax Oil and gas production tax	Fisheries business tax Fishery resource landing tax Mining license tax Oil and gas properties production tax Salmon enhancement tax Salmon marketing tax Seafood marketing assessment	Severance tax	Natural resources severance tax Oil and gas conservation assessment Tax on minerals or timber taken from state lands	Oil and gas production tax Timber yield tax
Colorado	**Connecticut**	**Delaware**	**Florida**	**Georgia**
Oil and gas conservation tax Severance tax	(No taxes imposed)	(No taxes imposed)	Oil, gas, and sulfur production tax Solid minerals tax	Tax on phosphates
Hawaii	**Idaho**	**Illinois**	**Indiana**	**Iowa**
(No taxes imposed)	Additional oil and gas production tax Oil and gas production tax Ore severance tax	Timber fee	Petroleum production tax	(No taxes imposed)
Kansas	**Kentucky**	**Louisiana**	**Maine**	**Maryland**
Mined-land conservation and reclamation tax Oil and gas conservation tax Severance tax	Coal severance tax Natural resource severance tax	Freshwater mussel tax Natural resources severance tax Oilfield site restoration fees	Mining excise tax	Clam and oyster severance tax Local taxes Mine reclamation surcharge
Massachusetts	**Michigan**	**Minnesotax**	**Mississippi**	**Missouri**
(No taxes imposed)	Gas and oil severance tax	Local taxes Mining occupation tax Net proceeds tax Semitaconite tax Taconite, iron sulphides and agglomerate taxes	Local taxes Oil and gas severance tax Salt severance tax Timber severance tax	Assessment on surface coal mining permittees

Table 4 (continued). States with Severance Taxes[32]

Montana	**Nebraska**	**Nevada**	**New Hampshire**	**New Jersey**
Cement license taxes Coal severance tax Metaliferous mines license tax Micaceous minerals license tax Oil and gas conservation tax Oil and natural gas production tax Resource indemnity trust tax	Oil and gas conservation tax Oil and gas severance tax Uranium tax	Minerals extraction tax Oil and gas conservation tax	Refined petroleum products tax	(No taxes imposed)
New Mexico	**New York**	**North Carolina**	**North Dakota**	**Ohio**
Natural gas processor's tax Oil and gas ad valorem production tax Oil and gas conservation tax Oil and gas privilege tax Oil and gas severance tax Resources excise tax Severance tax	(No taxes imposed)	Oil and gas conservation tax Primary forest product assessment	Coal severance tax Oil and gas gross production tax Oil extraction tax	Oil and Gas Marketing Program Assessment Resource severance tax
Oklahoma	**Oregon**	**Pennsylvania**	**Rhode Island**	**South Carolina**
Oil, gas, and mineral gross production tax and petroleum excise tax	Forest products harvest tax Oil and gas gross production tax Privilege tax on eastern Oregon timber Privilege tax on western Oregon timber	(No taxes imposed)	(No taxes imposed)	(No taxes imposed)
South Dakota	**Tennessee**	**Texas**	**Utah**	**Vermont**
Conservation tax Energy minerals severance tax Precious metals tax	Coal severance tax Local taxes Oil and gas severance tax	Cement production tax Gas production tax Oil field cleanup regulatory fees Oil production tax Sulphur production tax	Oil and gas conservation tax Severance taxes	(No taxes imposed)
Virginia	**Washington**	**West Virginia**	**Wisconsin**	**Wyoming**
(No taxes imposed)	Enhanced food fish tax Uranium and thorium milling tax	Severance taxes	Mining net proceeds tax Oil and gas severance tax	Mining excise and severance taxes Oil and gas production charge

Source: National Conference of State Legislatures

2.1.7.1.1 Use of Severance Tax Revenue

When the proceeds of a severance tax are placed directly into the general fund, it can create substantial incentives on the part of policymakers to spend the new money. Aside from the obvious profligacy of such behavior, other problems can arise. In brief,

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[32] The leap in crude oil prices recently has had a noticeable effect on state severance tax collections reported to the Census Bureau. In 16 states, severance taxes accounted for at least 1 percent of state tax collections in 2007, with Alaska leading the pack (Zelio and Houlihan).

such spending can exacerbate general, localized, and sectoral inflation, it can exhaust the compensation for the sale of a given state's patrimony, and the money can create a more onerous social spending burden which, when the source of new revenue potentially dries up in the future, can inadvertently cause contraction or cessation of services upon which citizens have come to rely.

2.1.7.1.2 Severance Taxes as Economic "Brakes"

The imposition of some form of severance tax upon the Marcellus development may or may not dramatically impair economic development in Pennsylvania. If the Considine reports are to be believed, there may be a reduction in how quickly the Marcellus will be developed. While this debate is still ongoing, the imposition of a severance tax will not prevent development of the MSF in Pennsylvania, as has been seen in all other states with oil and gas development. Pennsylvania is the only state with appreciable oil or gas production that has not imposed some form of severance on extraction. The fact that development has proceeded everywhere else in the US with the presence of a severance tax undermines the argument against a severance tax.

While the severance tax may reduce the rate of development (particularly if Considine's report is correct), this may be a more prudent long-term strategy. As that report states:

> [T]his [severance] tax cannot be passed on to consumers and, therefore, drilling activity would decline by more than 30 percent and result in an estimated $880 million net loss in the present value of tax revenue between now and 2020. Severance tax revenue gains are more than offset by declining state and local income taxes resulting from lower drilling activity under the severance tax. The high level of drilling activity in Pennsylvania is a function of relatively lower taxes. This competitive advantage should be maintained as the Marcellus competes for capital and labor with other shale plays around the nation. Imposing a severance tax at this early stage of development could significantly inhibit the growth of

> the Marcellus gas industry in Pennsylvania (Considine et al. "An Emerging Giant" ii).[33]

One of the main problems with the resource curse is the rate of development vis-à-vis the rest of the economy. This is highly dependent upon the overall price of gas, specifically the Henry Hub[34] price and including any royalty and extraction taxes. This is important to note, since a severance tax amounts to what is essentially an additional production cost directly to the natural gas industry.[35] This is because these costs cannot be passed on to the end user, thanks to the competitive nature of the gas market at large. If the imposition of the severance tax could potentially temper the exuberance with which gas extraction companies rush into the MSF, conceivably much of the pain associated with natural resource extraction could be minimized to some degree. This reduction in development would be a short-term development. Since the price of natural gas is likely to both

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[33] To elaborate, Considine's argument against imposing a severance tax is based on the assumption that Marcellus development in Pennsylvania should occur as quickly as possible in order to maximize the potential economic benefits. However, as the literature that addresses the Dutch Disease emphasizes, the speed at which resource extraction occurs can have dramatic effects upon the sectoral and locality-based externalities. Therefore, if the aim of Pennsylvania lawmakers is to create a sustainable model of development that both allows for resource extraction and aims to mitigate the works excesses of Dutch Disease/resource curse externalities, it stands to reason that slowing down natural gas development may, in fact, be a viable public policy approach. This, of course, assumes that Considine's argument about the potential effects of the imposition of a severance tax are correct.

[34] Henry Hub is the convergence point for a number of major American natural gas pipelines. When speaking of Henry Hub pricing, this term refers to Henry Hub as the pricing point basis and official delivery point for American natural gas futures contracts trading on the New York Mercantile Exchange (NYMEX).

[35] It is important to note that severance taxes represent but one variable that companies consider when determining where to develop hydrocarbons (or other extractive resources). While the argument could be successfully made that, all other variables being equal, severance tax rates will determine the competitiveness or financial viability of developing a given resource, rarely – if ever – will that be the case. Once again, this has been observed in all other states that have oil or gas development. All except Pennsylvania have imposed severance taxes on the oil and gas industry operating in their boundaries.

become more volatile and generally rise as the demand for the fuel rises and the penetration into the market for more diversified uses increases, it makes sense to curtail the ramping up of production so that the rents[36] of the resource can be maximized. This would place Pennsylvania in good company with other resource-extractive economies the world over, including Saudi Arabia, Kuwait, and Venezuela,[37] among others. Such rent-maximizing behavior (as opposed to profit-maximizing behavior) in the natural gas market will likely have a similar price-stabilizing effect on the natural gas market as it does on the oil market. While volatility cannot be eliminated altogether, minimizing it makes formulating policy considerably easier in the long run.

2.1.7.2 Natural Resource Funds (NRFs)

In the United States, twenty-six states have substantial amounts of resource extraction-based development.[38] Many nations also find themselves in a similar set of

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[36] The term *rent* refers to the financial return received by the owner of a given property in excess of the cost of production/maintenance. In this case, rents refer to the return received from the development of some natural resource (e.g., natural gas, oil) that exceeds the costs of production for said resource. More commonly, the term is typically employed in relation to real estate, whereby tenants will pay a set rate for using the property, and represents return over and above the capital appreciation and the cost of maintenance for that property.

[37] Dag Harald Claes, in his now-famous work "The Politics of Oil-Producer Cooperation" delves deeply into this subject, making the argument that, with few exceptions – namely Kuwait – oil-producing nations have an economic incentive to maximize rents rather than profits. This is due in large part to the fundamental difference between profit-maximizing corporations, whose main (only?) bottom-line concern is profit-maximization, and the manifold concerns facing oil-producing nations.

[38] There is no standard percentage to which to refer when speaking of substantial levels of economic activity based upon resource extraction. There are many variables to consider. For some nations, like Venezuela, rely heavily on extractive industries. Approximately one-third of Venezuela's total GDP, four-fifths of its exports, and more than half of all government revenues are due to petroleum extraction and associated industries. On the other hand, approximately one-fifth of Norway's GDP and almost half of total exports is due to oil or natural gas ("CIA World Factbook – Norway," "CIA World Factbook – Venezuela," "Norway," "Venezuela").

circumstances, with large portions of their overall economy based upon natural resource extraction. The percentage of a given nation's overall economy that is dependant upon resource extraction can vary greatly, but all of them will be subjected to the complications of this type of development to some greater or lesser extent.

Many of the problems these states have experienced are microcosms of the issues facing entire nations that base large portions of their economic activity upon resource extraction. The states, just as the nations, suffer many ills. Dutch Disease and price volatility rank high on the list of concerns, just as infrastructure costs, environmental degradation, and sectoral and micro-inflation do. These states would do well to consider public policies that many of these nations have chosen to pursue. According to Tsalik and Ebel, NRFs can be an effective policy mechanism for stabilizing government spending and revenues, particularly in light of the volatile nature of commodity markets. Moreover, NSFs can help mitigate complications arising from the Dutch Disease by "sterilizing" royalty revenues by preventing the injection of substantial amounts of export revenues from entering the domestic economy, thereby preventing the problems arising from hard-currency-driven inflationary pressures from overheating the economy (Tsalik and Ebel 6).

Moreover, NRFs can also be employed in multiple ways to serve a multitude of public policy goals. Typically, NRFs are employed as either stabilization funds or as future savings funds. Some governments choose to employ NSFs for both purposes. Stabilization funds can be employed to "smooth out" government expenditures by

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redirecting tax or royalty revenues to the NSF when commodity prices rise, providing a source of additional revenue for the government in question when resource prices – and their concomitant revenues – fall (Tsalik and Ebel 18). By providing a mechanism to divert and invest revenues when commodity prices rise, a given government then has a fund set aside to reliably fund future policy initiatives, even in a sustained period of low prices or high price volatility.

Another major concern of governments dependent upon resource extraction is the prospect of exploiting its citizens' patrimony, either through outright profligacy, or through the natural depletion of a given limited, non-renewable resource. Natural resources, typically by their very nature, are scarce and non-renewable. By acknowledging this fact as well as embracing the idea that these depletable resources also belong to future generations, the establishment of a NSF for use as a savings fund or "future generations" fund can allow for the storing of wealth to be used by future citizens. By creating a storehouse of wealth and then using that wealth to generate a stream of income, the NSF operates in much the same way as pensions operate for individuals (Tsalik and Ebel 18). In addition, by setting aside a portion of the proceeds from the royalty payments, a given government can protect against the short-term exhaustion of the resource royalty windfall resulting from extraction.

Many nations around the world,[39] as well as the state of Alaska, have instituted NRFs to better mitigate and manage the attendant effects of resource extraction. Many have been successful, and some certainly more than others.

2.1.7.2.1 Importance of bringing stakeholders to the table

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[39] Some examples include Norway, Azerbaijan, Kazakhstan, and Russia (Tsalik and Ebel).

NRFs also provide the potential for bringing stakeholders to the decision-making table, rather than allowing the decisions for spending those funds to be made without direct public scrutiny. This allows for consideration of the potential impacts to stakeholders and their non-financial concerns, such as: environmental, water usage, local infrastructure degradation, socio-demographic changes, local economic, health and safety, consumer protection, legal and regulatory effects, local governmental responsibility, local service demands, etc.[40]

2.1.8 Boom and Bust Cycles

The modern hydrocarbon era began in Pennsylvania on August 28, 1859, when "Colonel" Edwin Laurentine Drake struck oil outside of Titusville, Pennsylvania (Green). From those inauspicious beginnings, American and world oil and gas development began in earnest. Today, Pennsylvania stands at the cusp of yet another hydrocarbon revolution, one that will move the market from a climate dominated by oil to one dictated by the supply of natural gas. The original strike in Pennsylvania led to an abrupt boom, and an even more abrupt bust, leaving many Pennsylvanians in worse shape than before the oil strike. With Marcellus shale production, the development is promising wealth, jobs, cheaper energy, greater national energy independence, and a new future for the state.

Yet the history of Titusville still lingers. Many Pennsylvanians seem stricken with fear of what this new hydrocarbon development might bring – and not without good

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[40] Just because NSFs provide potential for bringing stakeholders to the table, this should not be mistaken as a guarantee for such interaction. Indeed, much research indicates that political corruption, perhaps more than any other variable, determines the degree to which stakeholders can be brought to the policy negotiation table.

reason. The fruits of this development very well could be as arbitrarily enjoyed as those from Drake's play.

Oil in particular has seen its volatility skyrocket as a direct result of its dual nature as a commodity and a financial instrument (Moors). As natural gas phases in as another "dual use" resource, it will likely become subject to similar market forces. A quick look at the general trend over the period from 1989 to 2005 for both natural gas and oil prices illustrates how the prices of oil and natural gas are related. The following graphical depiction shows overlays of historical Henry Hub prices with West Texas Intermediate (WTI) crude prices.[41]

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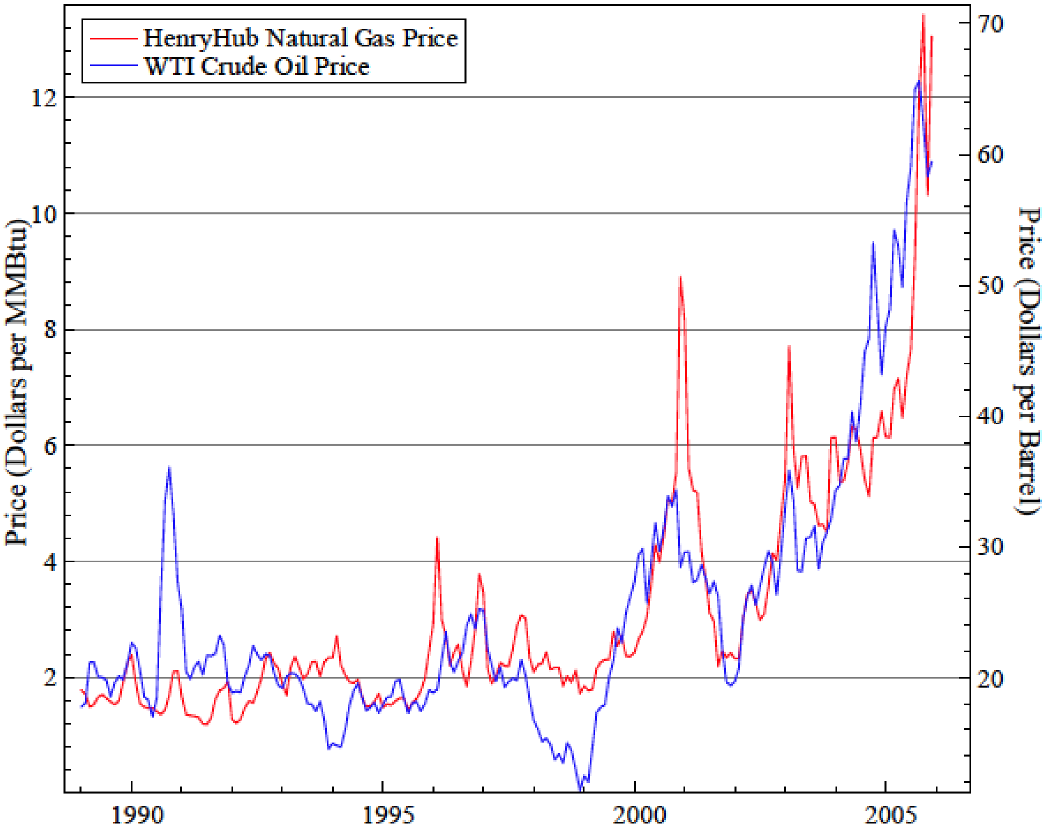
[41] West Texas Intermediate refers to the type and quality of oil historically extracted from Texas, particularly in the Permian Basin of West Texas. WTI oil has traditionally been of high quality, exhibiting both relatively low density and low sulfur content. Hence, the use of the phrase "light, sweet" when referring to oil quality. High-density oil, like what is typically found in the Orinoco Basin in Venezuela, and sour crude, like what is typically found in Saudi Arabia, tends to sell at a discount to the benchmark pricing. WTI has been used as the benchmark for North American crude oil pricing on the NYMEX, whereas Brent pricing (from the North Sea) is used as the benchmark for European, African, and Middle Eastern crude oil pricing ("Brent Crude," "North Sea," "West Texas Intermediate (WTI)," "West Texas Intermediate – Wikipedia").

Figure 1. Henry Hub and West Texas Intermediate Prices (1989-2005)



Source: Energy Information Administration, *Short-Term Energy Outlook*, various issues.

The 1859 Pennsylvania oil strike at Titusville provides us a further a case in point ("ExplorePAHistory.com"). While many in Pennsylvania may see the original American oil strike and subsequent development as a case for considerably stronger environmental protection, it likewise provides an example of unregulated and unmitigated economic development which, when not managed properly, leaves an economic wasteland in its wake. As covered previously, it is clear from the historical record that extractive industry has a tendency to unleash many uncontrolled and unanticipated forces upon given localities. Not only did the Titusville strike create vast fortunes and cause horrible environmental damage, it also wiped out entire towns and populations when the oil dried up. Such boom-bust industrial development plays havoc with proper policy management, and very well could lead to choking off all other surrounding economic activity, even if that economic activity seemingly has no connection to the extractive industry in question.

In addition, Alaska's recent write-down of oil reserve figures provides a more recent example of the drawbacks of price volatility (Heimel). When a number of oil companies operating in Alaska wrote down their oil reserve estimates, the state found itself in the unenviable position of having a large portion of its expected future revenues from oil extraction evaporate overnight. As a result, Alaska now faces substantial budgetary and economic crises that will worsen going forward. In this case overly optimistic estimates were given; but reality has led to a future fund shortfall (Levisohn).

2.1.9 Gas Pricing and Volatility

Aside from the most recent and precipitous drop in world natural gas prices – which was fundamentally unrelated to the energy markets[42] – there has been a sharp and substantial increase in the overall price of natural gas since 2001. Three major causes for this boom include demand growth, gas-oil linkage, and speculation.[43]

There are many factors that help determine natural gas prices. The following is a list of many of the some of the largest considerations for determining gas prices (Gilardoni 116-20):

Price seasonality
Cost of production, transportation, storage, and distribution

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[42] The primary reason for the drop in natural gas prices since 2008 owes more to the overall world economy – and the subprime mortgage bubble's effect on it – than new natural gas production. Only now is the economy recovering to levels approaching pre-recession levels.

[43] "These contracts, historically fundamental to investments in infrastructure, are still very important even though in the last ten years the spot and forward markets have grown in importance. The structure of these contracts allows a change in prices, with a certain delay, changes that are very often indexed to oil prices" (Gilardoni 6).

Region/country specificity
Political relationships between parties and nations
Size/type of customer
Contractual structure of supply agreement
Oil linkage
Risk markets and speculation
Regulations
Taxation
Balance of supply and demand
National events
Market expectations

As one can imagine, many of these factors can be either endogenous or exogenous, depending upon a number of issues. There again, such lack of uniformity in the gas market – which the expansion of the LNG market and more sustained and converging gas prices should remedy – makes price volatility a rather major concern, particularly for policymakers who depend upon revenues and royalties from natural gas extraction and production.

One of the primary ways in which gas prices are determined is by the market for natural gas that is established by “take-or-pay” contracts.[44]

Speculation has a dramatic effect upon natural gas prices for many reasons. For the purpose of this work, the important point to remember is that, while speculation is critical to maintaining market liquidity, the speculation itself has a tendency to drive

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[44] Take-or-pay contracts are structured in such a way that the contract purchaser must either accept the goods under contract, or suffer some pre-contracted penalty.
The importance of these contracts was, of course, seen in the recent diplomatic blow-up, no pun intended) between Russia and Turkmenistan, when Gazprom essentially refused to honor the agreed-upon take-or-pay agreements. Mysteriously the pipeline pressure between the two nations fluctuated slightly, leading to a rather dramatic and coincidental gas explosion on the border between the two former Soviet republics.

prices upward. According to some sources, the real effect of speculation may be a net increase in the price of natural gas of over 30%.[45]

More important than the amount of speculation is the type of speculation – enormous bets by non-traditional, e.g., hedge funds and other non-end-users, causes more market volatility rather than less volatility, as one might expect with an increase in the volume of speculation.

According to Gilardoni, there are at least two different theories about the evolution of natural gas prices. The first theory is based on the historical trends of oil prices, and their tendency to follow a pattern of extended waves, i.e., long-term price increases followed by long-term price decreases. The second theory is based on the assumption that changes in hydrocarbon prices are structural in nature, due in large part to changes in the political relationships between the producing and consuming countries. The demand for energy will steadily grow, resulting in a constant pressure on supply, pushing prices ever higher (Gilardoni 8).

Both of these theories carry a fair amount of weight, insofar as they both are empirically based and describe, to some degree, how the oil and gas markets have behaved in the past. However, rather than being at odds with one another, these mechanisms in actuality function in conjunction with one another, for a variety of reasons. As Moors' research into oil volatility and the last three years demonstrates, these long waves will be punctuated by extreme fluctuations in oil prices – due to oil's dual

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[45] "A US Senate investigation demonstrated the negative impact of uncontrolled speculation by increasing real prices, with damaging consequences for businesses and families. According to some analysts, although it is very difficult to calculate, the extent of speculation has grown dramatically in the last five years, reaching levels in excess of US $100 billion for the US market alone" (Gilardoni 6).

nature as both a commodity and a financial instrument – and the two trends mentioned above will serve as mutually reinforcing attributes of the overall energy markets. As this hyper-volatility compels much of the industrialized world to move into a post-petroleum scenario, in which the fuel source of choice for electricity production and transportation will no longer be coal and oil, respectively, one can expect the same rules of volatility to eventually apply to natural gas as they seem to apply to oil in the current climate. This volatility, particularly from a budgetary and macroeconomic perspective, must be addressed directly, otherwise succumbing to the resource curse becomes an ever greater potential developmental threat.

There can really no longer be talk of domestic energy markets without addressing their place within the larger context of the world energy market. The respective domestic markets are becoming ever-more intrinsically linked, and are affected by the goings-on within other nations and, more importantly, regional markets. Regional markets have increased in importance due in great part to the lack of a unified world market and lack of a distribution network like what oil has developed over the past century. This, however, is changing almost daily. With the adoption of LNG use and production worldwide – Qatar led the way by turning all of its natural gas production to LNG right before the recent international economic collapse – soon natural gas will be every bit as fungible, and considerably more abundant than oil.

Therefore, there is currently no single baseline price for natural gas, and no single global gas market. Historically, the gas market has been regional and pricing largely local.

As Gilardoni notes, the United States in particular led the way developing natural gas production and usage due mostly to the presence of the largest and most technologically and financially advanced oil and gas companies on the planet, specifically ExxonMobil, ConocoPhillips, and Chevron (22). Despite the fact that American conventional gas production peaked somewhere during 2001, American unconventional gas production has yet to really even begin. This is in addition to the fact that, despite reaching peak production, the US still maintains substantial conventional reserves. Thus, just as the US led the way in developing its conventional reserves, so it likewise leads the world in unconventional development, and also can claim substantial – albeit not the largest in the world– unconventional reserves in the form of shale gas, tight gas, coal-bed methane, and methane hydrates. In fact, it is entirely conceivable that total US natural gas production (conventional and unconventional) will increase well beyond the levels reached by conventional production only (Gilardoni 22).

The current US "energy mix," or rather the proportion of energy the US employs from various sources, has not changed dramatically over the previous thirty years (Gilardoni 42). However, this will undoubtedly change soon, as new rules recently passed by Congress will go into effect starting at the beginning of 2012. These new rules will essentially force the mothballing of a number of coal-fired plants, since retrofitting the requisite scrubbing technology remains terribly cost-prohibitive, particularly for the older plants. Some have predicted that natural gas usage will increase substantially in order to make up the difference in power generation.

Particularly until the gas market can truly be called an international market, one of the most important single factors determining the price of natural gas is its linkage to oil prices (Gilardoni 127). This so-called "gas-oil linkage" is due in large part to the pricing of take-or-pay contracts for natural gas, which are essentially long-term contracts, generally between large producers and consumers. These take-or-pay contracts have historically been based upon oil prices, and generally are agreed upon for periods often in excess of decades.

While the individual spot markets are beginning to develop into a more comprehensive system, thanks in large part to more and better sources of LNG, much of the price of natural gas remains determined by this contract price linkage to oil. In the intermediate term, while the global natural gas market establishes itself but is still heavily impacted by oil prices, it will be interesting to see precisely how much the predicted volatility of oil will affect natural gas prices (Gilardoni 131-2).

2.1.10 Short Term vs. Long Term Production Potential

Another concern related to the development of natural resources, but specific to shale gas extraction – as well as deepwater oil and gas, and other types of unconventional gas development – is the comparatively high front-end production of the resource in question, and the way in which it stands in stark contrast to production in later years. As much as 60% of the total extractable natural gas volume from a given well will be extracted within a period of between 18 and 36 months from the initial well spudding (Considine et al. "An Emerging Giant" 6). One need only compare the depletion curves of the examples cited above with those of more "normal" hydrocarbons, such as conventional natural gas or onshore oil, to get a sense of the problem. Due to the highly front-end-loaded extraction, many of the potential benefits of shale gas extraction could easily be mitigated by the negative effects that such development would entail. Therefore, policymakers should strongly consider this aspect of shale gas development before making long-term plans on any number of policies.

2.2 A Changing Landscape: How Pennsylvania's Resources are Impacted

The MSF will undoubtedly have a profound effect, both positive and negative, on Pennsylvania. This has been witnessed in other shale gas developments in the U.S., particularly in the Barnett and Haynesville formations. It stands to reason that, to some greater or lesser degree, the development experiences in those places will likely provide indications as to what will happen moving forward in the Marcellus.

2.2.1 Previous US Shale Gas Development

As noted previously, the MSF development follows the Barnett and Haynesville formations as major shale gas developments in the United States. Of these two, the Barnett shale formation (BSF) is the larger and older play.[46] The BSF covers approximately 5,000 square miles of the north-central part of Texas. Figure 2 shows the location of the primary production area of the BSF in Texas.

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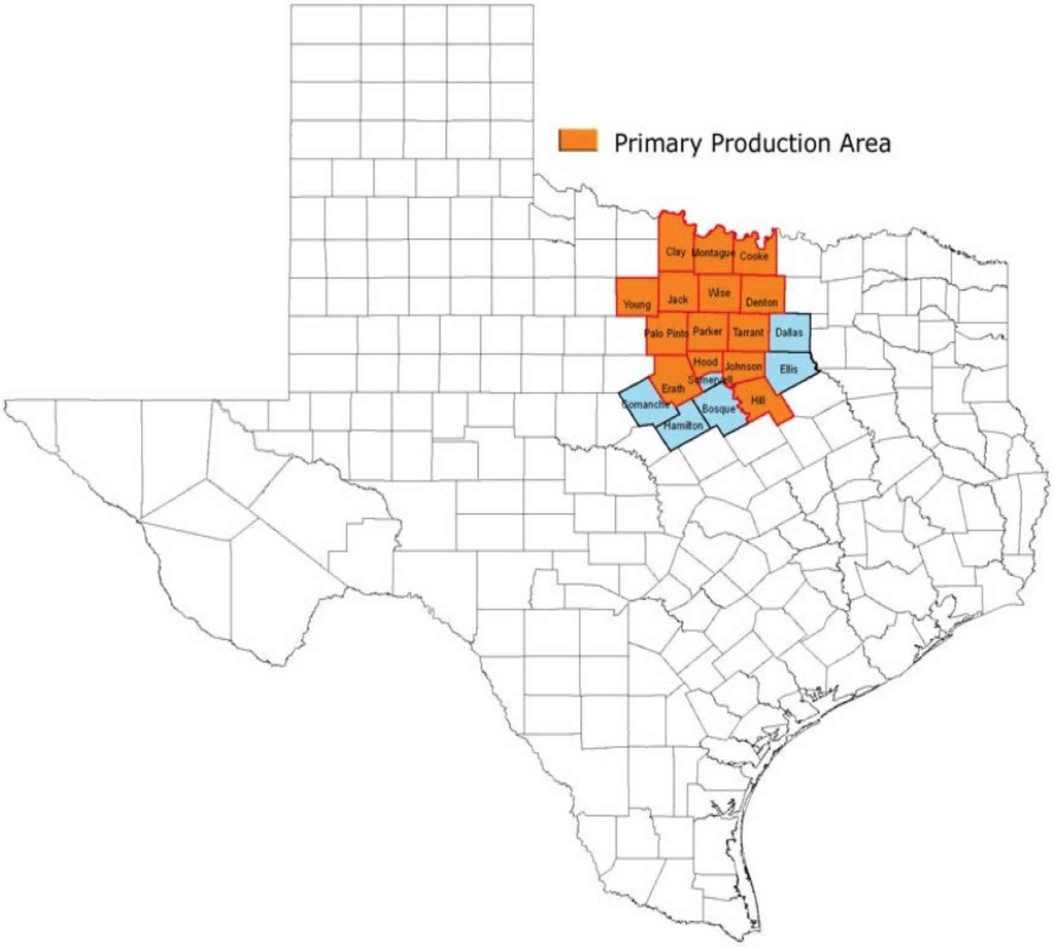
[46] "Natural gas production from shale deposits began during the 1980s with the development of the Barnett Shale play in the Fort Worth, Texas region. During 2008 this field alone produced 3.8 BCF per day. Just five years prior in 2003, it produced 0.8 BCF per day" (Considine et al. "An Emerging Giant" 5).

Figure 2. Barnett Shale Formation Location Map



Source: The Perryman Group ("Barnett Shale Impact Study")

Barnett development began in 1981 with the spudding of vertical wells, and proceeded eventually to the developmental convergence of horizontal drilling and hydrofracturing into a single process. The Barnett, it has been said, has become the true "proving ground" for economically viable shale gas development ("Shale Gas Reservoirs").

Based on a recent economic impact report on the BSF development published in 2009, "[t]here are more than 10,500 wells and 222 companies operating in the Barnett Shale…. In 2008, the Barnett Shale generated 111,131 permanent jobs and pumped more than $11 billion into the regional economy, a net gain of more than 30 percent over the previous year" (Bennett "Barnett Shale").

The well and job data on the BSF provides a conservative starting point for estimating expected output in the MSF. Considine, Engelder, and Lash, along with most other analysts dealing with the MSF, have based their estimates of the MSF on the BSF. Therefore, the BSF, with relatively smaller size and less-rich deposits compared to the MSF, can give a conservative estimate of what to expect moving forward as development proceeds in the MSF.

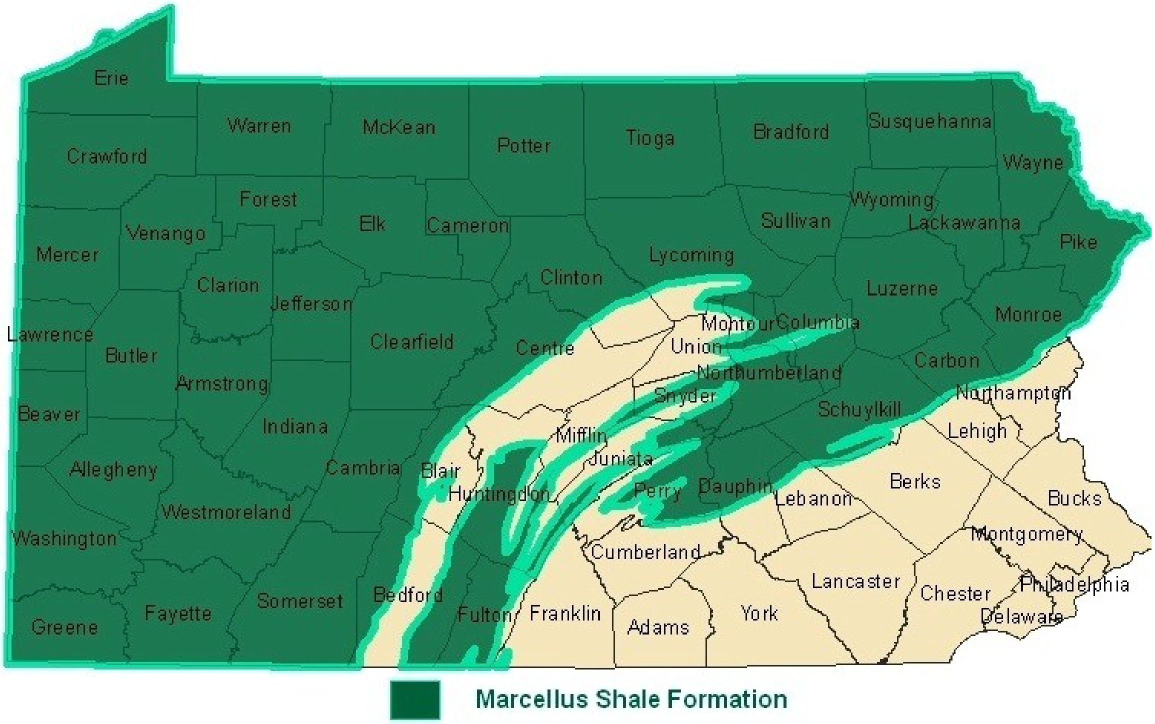
As beneficial as the Barnett (and the Haynesville) development has arguably been for their respective economies, a more balanced and broader view should be taken when discussing the more localized conditions and attendant problems there. Whitmer and Brasier opined that local conditions – particularly economic, environmental, and infrastructural – will have profound impacts on the exploration and development of natural gas. Moreover, due to the variations in those conditions between and among various localities where shale gas development is taking place, the policy options available to each particular locality will differ considerably (Whitmer and Brasier).

While the development of the MSF will benefit some areas and negatively impact others, the benefits certainly will not accrue equally or uniformly. Indeed, some areas, or even entire regions, may receive little if any benefit to the development and experience many of the negative attendant effects, whereas other areas very well could experience rather outsized benefits and yet experience few, if any, of the negative externalities. Such asymmetrical or unfair outcomes necessitate statewide public policy action in such circumstances.

2.2.2 Marcellus Shale Specifics

Marcellus shale[47] is a type of stratified rock located approximately a mile beneath the surface of the earth, stretching from southern West Virginia through Ohio and Pennsylvania into southern New York state. Figure 3 shows the extent of the Marcellus formation in Pennsylvania.

Figure 3. Marcellus Shale Formation Location Map



Source: Pennsylvania Department of Environmental Protection

The shale has a substantial percentage of organic material which, when correctly developed, yields copious amounts of natural gas. That gas can then be used for a host of ends. The Marcellus formation is the largest shale gas formation of its kind in the world. To put this into perspective, it contains an estimated almost 500 trillion cubic feet (TCF)

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[47] "The Marcellus shale is an organic-rich black shale that was deposited in an oxygen-deficient marine environment during Middle Devonian time (~390 million years ago)" (Harper).

of *in situ* natural gas reserves. The amount of extractable volume continues to climb, from the initial estimates ranging between 75-100 TCF to the more current estimates[48] that surpass the initial estimates by more than 100%. The initial estimates of extractable volume of natural gas could conceivably supply the entire United States' natural gas needs for over two years (Engelder), whereas more recent (and admittedly less conservative) estimates could provide as many as 20 years' worth of domestic natural gas demand. The United States currently consumes more natural gas than any other nation in the world – almost twice as much as Russia, the next nation on the list. Thus, even if only the lower estimates prove accurate, the volume of extractable gas being discussed here could have profound effects upon the natural gas market, worldwide.

The Marcellus, like the Barnett and the Haynesville plays, also requires highly specialized geo-engineering techniques in order to develop and extract the gas trapped within it, particularly hydrofracking and horizontal drilling.

2.2.2.1 Justifications for MSF recoverable volume

Many experts have proffered numerous estimates of recoverable natural gas volume for the MSF. These estimates have varied from the low end of 25 TCF to upwards of 400 TCF. While all of these various estimates have some basis for justification, the most statistically sound (and credibly conservative) estimate comes from Engelder and Lash:

> Given a resource that is found under more than 34,000,000 acres of real estate with at least 50 feet of organic-rich section, the Marcellus Shale weighs in with more than 500 trillion cubic feet of gas in-place spread over a four state area. Continuous natural gas accumulations such as the Barnett Shale produce more than 10 percent of the gas in-place, which

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[48] Moors and other sources predict volumes ranging from 150 TCF to as much as 500 TCF of extractable volumes.

> when applied to the Marcellus Shale, translates to a resource that will return 50 Tcf in time. Confusion arises when this figure for technically recoverable gas is compared with the U.S. Geological Survey's prediction of 1.9 Tcf for an undiscovered resource in a portion of the Marcellus. The two numbers should not be compared, since the USGS figure relies heavily on knowledge of the ultimate recoverable gas per well. Because there has been little production from the Marcellus, the USGS figure is inherently low, but will begin to climb when production comes on line. Production from the Huron/Dunkirk interval of the Big Sandy Field has enabled the USGS to predict an undiscovered resource of 6.3 Tcf. This field has less than 25 percent of acreage found within the boundaries of the Marcellus play, and the average depth of the Big Sandy Field is less than that of the heart of the Marcellus play. The scaling factor between the Big Sandy Field and the Marcellus play is about eight, which means that all else being equal, extrapolating the Dunkirk/Huron play suggests a total resource of the Marcellus play of nearly 50 Tcf. With this extrapolation, the USGS and Engelder-Lash estimates are in agreement. (Engelder and Lash).

Based on the Engelder/Lash estimates, the Marcellus formation potentially holds enough natural gas to turn the state into a net exporter of natural gas, rather than a substantial importer. While this may sound a bit underwhelming, it must be kept in mind that this amount of an available natural resource amounts to substantial market power in the form of commodity price stability and national security. Moreover, from the standpoint of statewide economic development, this price stability will make budgetary decisions considerably easier to make, since it is the potential volatility in price as much as the additional economic activity and other attendant issues that leads to difficult budgetary and economic pressures. As a result, policymakers must place themselves in a position to determine the most publicly favorable means of development, in order to most positively affect the eventual outcomes of this new industrial development.

2.2.3 Road Maintenance and Water Usage: Study Variables

2.2.3.1 Road Infrastructure Issues

Practically all industrial development involves the imposition of negative externalities to the surrounding environment to some degree. Mineral extraction in general, and oil and gas development in particular, causes a range of different types of negative externalities. Drilling of any kind requires the use of heavy equipment, which must be trucked in by large tractor-trailer trucks. Roadway damage is an expected result of drilling as a result.

On September 30, 2009, the Department of Environmental Conservation (DEC) of the state of New York issued the Supplemental Generic Environmental Impact Statement (SGEIS), addressing numerous issues and complications arising from potential natural gas drilling activities in the Marcellus Shale formation. The following is a listing of the estimated truck trips necessary in order to develop a single shale gas well ("Marcellus Shale gas"). The trips have also been broken out by the respective phase of activity and the number of trips per phase.

Drilling Rig Mobilization, Site Preparation and Demobilization

- Drill Pad and Road Construction Equipment 10 – 45 Truckloads
- Drilling Rig 30 Truckloads
- Drilling Fluid and Materials 25 – 50 Truckloads
- Drilling Equipment (casing, drill pipe, etc.) 25 – 50 Truckloads
- Completion Rig Mobilization and Demobilization
- Completion Rig 15 Truckloads

Well Completion

- Completion Fluid and Materials 10 - 20 Truckloads
- Completion Equipment (pipe, wellhead) 5 Truckloads
- Hydraulic Fracture Equipment (pump trucks, tanks) 150 - 200 Truckloads
- Hydraulic Fracture Water 400 - 600 Tanker Trucks
- Hydraulic Fracture Sand 20 - 25 Trucks
- Flow Back Water Removal 200 - 300 Truckloads
- Well Production
- Production Equipment 5 – 10 Truckloads

As soon as drilling begins at a given location, traffic increases dramatically. As mentioned above, this traffic primarily consists of extremely heavy truck traffic. The first truckloads bring in heavy excavation equipment. If the wellsite is located in forested area, like much of the development in Pennsylvania, then the equipment also includes forestry equipment. The excavation equipment is used to prepare the wellpad site, where the bulk of the drilling activity will take place. After creating the egress roads and grading the wellpad site itself, hundreds of tons of gravel are trucked in, both for the wellpad itself and for the access road.

Once the wellpad has been fully prepared, many more trucks – all extremely heavy, weighing many tons each – haul in the drilling rig, which will enable the horizontal drilling process that makes shale gas economically feasible in the first place. Of course, once the drilling of the well has been completed, this equipment must be hauled away from the drilling site to make space for the equipment and water needed to perform the hydraulic fracturing, which actually releases the bulk of shale gas for extraction. As is often the case, multiple wells may be drilled and fracked from the same wellpad, adding to the amount of traffic with which a given location must deal. The fracking process includes various types of equipment, from the actual high-pressure pumping equipment to water holding tanks, tanker trucks, support trucks, sand trucks, etc. ("Road damage").

Based on the information above, each shale gas well requires at least 905 separate truck trips, and potentially as many as 1,320 – the bulk of which is primarily water. The number of truckloads needed to frack wells ranges from 476-667 trips (at 3 million gallons) to 714-1,000 trips (at 4.5 million gallons).

Water represents the single most traffic-intensive component of shale gas development, but certainly is not the only issue. In fact, while water as a factor of production represents the highest number of truck trips, some of the excavation and drilling equipment needed to prepare the wellpad and drill the well can be considerably heavier than water loads. However, since water is the single largest factor in fracking a shale gas well, it seems to make sense to consider that facet of the process more closely.

According to Chesapeake Energy's website, the water trucks most often used in shale gas development can transport volumes of water between 4,500 and 6,300 gallons per load. The volume depends upon the specific models of trucks used by a given operator company. At 70 degrees Fahrenheit, the weight of water per gallon equals 8.3290 pounds. Therefore, a 6,300 gallon tanker truck would carry as much as 52,472.7 pounds of water. The weight of the water is in addition to the weight of the truck itself, which can exceed 28,000 pounds on its own. With truck and water combined, the total can often exceed 80,000 pounds, which exceeds the legally allowed maximum weight for state and federal highways in both Texas and Pennsylvania. As noted above, to frack a single well requires hundreds of truckloads of water, whether a company uses 4,500 gallon, 6,300 gallon tankers, or something in between. The real variable here is how much water each individual well requires in order to successfully hydraulically fracture the underlying rock formation. By considering water loads, one can get a general picture of the types of damage this traffic can cause.

According to *The Handbook of Highway Engineering* by T. F. Fwa, the traditional planning of highways, from construction to maintenance, centered on "considered traffic mix repetitions and material properties as the primary input variables for structural designs" with little to no consideration for environmental effects or material degradation or maintenance scheduling over time (Fwa 18.16-17). When such heavy traffic activity like shale gas development – both in overall net tonnage of the vehicles and the frequency of that traffic – arrives to a given area, the overall stress placed upon the local infrastructure can overwhelm the design in a very short time. Thus, even when companies argue that the time period of heaviest activity of drilling in a given area will be limited[49], there will still be substantial damage done to the highway infrastructure, particularly if the roads and highways in question were not originally built to standards which will support such high axle weights or traffic volumes. As stated in Fwa 2006, "Heavy traffic load repetitions will in all cases accelerate damage caused by environmental factors and material degradation."[50] Therefore, according to Fwa the overall damage sustained by road infrastructure in areas of dramatic seasonal weather change will likely be considerably higher than otherwise would be the case when the stress of high-volume heavy traffic is added.

The critical point to consider, at least with regard to Marcellus shale development as it differs from Barnett shale development, is the overall climate and weather patterns involved. Pennsylvania typically has large seasonal changes, which have a dramatic effect on road surfaces. Weather and traffic have a tremendous impact on roads. Compare this weather-related complication of road maintenance to the seasonal changes in Texas, where seasons tend to be considerably less extreme and the weather itself is more

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[49] Chesapeake claims that the company is able to drill a typical Barnett Shale gas well in about 20 days ("Kennedale").

[50] Fwa goes on to state that "[t]hermal cracking in concrete slabs can be caused by three to four times larger tensile stress due to high temperature differential from the top surface to the bottom, compared to the load induced tensile stress. Low temperature thermal cracking of asphalt pavements is initiated by very low ambient temperatures. Pothole formation during spring-thaw season represents a good example of interaction of three mechanisms; load repetitions, weakening of sublayers and roadbed soil, and thaw (environmental) conditions" (Fwa).

conducive to maintaining healthy roads. As established above, when heavy traffic volumes and weights interact with climatological effects on road infrastructure, the end result is one of substantially higher maintenance and replacement costs. Thus, one would expect that, all other variables being equal, Pennsylvania will likely experience even greater infrastructure degradation resulting from shale gas development than Texas did in its development of the Barnett.

In the US, the public sector generally builds and maintains transportation infrastructure, particularly public highways. Highways have traditionally been the primary means of inter- and intra-state goods transport for decades. As public goods, roads and highways are generally available for all to use, with relatively few regulations. As usage increases, so do the associated costs for maintenance and network expansion, as the demand for deeper network penetration and overall road and highway quality increases.

As industrial usage increases, so do the costs of maintenance, particularly as the overall tonnage of cargo increases. For example, it stands to reason that a truck carrying drilling equipment or water needed for drilling and weighing many tons will degrade road surfaces and subsurfaces faster than normal highway traffic, all other variables being equal.

Moreover, such heavy traffic dramatically affects the strength of bridges. As a report by the Florida Department of Transportation stated, “gross weight, axle weight, and axle configuration of heavy trucks directly affect the service life of highway bridge superstructures” (Wang). This is particularly important in Pennsylvania, as there are a tremendous number of bridges in the state, due to the high number of rivers and streams throughout the state.

According to federal guidelines established for the National Interstate System, the maximum gross vehicle weight is 80,000 pounds. This weight restriction is further limited by per-axle weight limits.[51] The average weight limit for state highways in Texas generally are built to the same standards as federal highways (Luskin and Walton). However, on as many as 40% of what are commonly known as "farm-to-market" roads in Texas, gross vehicle weight is limited to 58,420 pounds. This justification of this weight limit standard is based on the fact that many of these roads were built many years ago, prior to the establishment of the current federal highway weight standards. Furthermore, a high number of bridges in Texas are load restricted, including as many as 4,000 that were built to standards that fail to meet the 58,420 pound standard for the farm-to-market road network (Stringer). The county and city roads and highways often fail to meet even the considerably lower weight standards of the farm-to-market network of roads. The end result of these lower standards amounts to higher levels of wear-and-tear on these

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[51] The following is an excerpt from the Federal Highway Administration's regulations: "658.17 Weight. (a) The provisions of the section are applicable to the National System of Interstate and Defense Highways and reasonable access thereto. (b) The maximum gross vehicle weight shall be 80,000 pounds except where lower gross vehicle weight is dictated by the bridge formula. (c) The maximum gross weight upon any one axle, including any one axle of a group of axles, or a vehicle is 20,000 pounds. (d) The maximum gross weight on tandem axles is 34,000 pounds. (e) No vehicle or combination of vehicles shall be moved or operated on any Interstate highway when the gross weight on two or more consecutive axles exceeds the limitations prescribed by the Bridge Gross Weight Formula, except that two consecutive sets of tandem axles may carry a gross load of 34,000 pounds each if the overall distance between the first and last axle is 36 feet or more. In no case shall the total gross weight of a vehicle exceed 80,000 pounds" ("CFR-2008").

highways, as they simply were not built for the types of tonnage wear caused by the water trucks used for water transportation for hydrofracking.

According to a report published by the Highway Research Board, NAS, in 1962, a single 40-ton (80,000 pound) truck does the amount of damage to road and highway pavement equivalent to 9,600 passenger cars. While many of the highways that have been laid down since 1962 are built according to higher standards than those built at earlier points in time, many of the highways and roads, particularly in rural areas, are built to the same standards that they always were ("The AASHO Road Test").

According to the U.S. Department of Transportation's Highway Cost Allocation Study, taxes on excessively heavy trucks – including water trucks and so-called "combination trucks"[52] – weighing 80,000 to 100,000 pounds only pay around half of the net cost of the wear and damage caused to roads and highways ("Highway Cost"). The report also found a negative correlation between the weight of these super-heavy trucks and the amount of damage the taxes assessed actually cover. In other words, as the weight of a given truck goes up, the less maintenance the taxes on that truck will actually pay for. For example, the study determined that taxes on trucks that weigh 100,000 pounds and above only pay for approximately 40% of the damage they cause. The result amounts to the spreading of maintenance costs to the general public, leading to further budgetary pressures ("Addendum").

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[52] According to BTS Transportation Expressions website, a combination truck is "a tractor pulling at least one full or semi-trailer or a single-unit truck pulling at least one trailer. (NHTSA3) (NHTSA4) Consists of a power unit (a truck tractor) and one or more trailing units (a semi-trailer or trailer). The most frequently used combination is popularly referred to as a 'tractor-semitrailer' or 'tractor trailer'. (ATA2) (DOE6)" ("Combination Truck").

In 2010, the state of Pennsylvania issued five citations to a single drilling contractor, totaling $31,304. The citations were issued because the drilling contractor was operating a truck that carried a gross weight of 89.7 tons – 179,400 pounds – despite only being registered for 40 tons (Wilber).

The rural roads and highways where most of the drilling in the Marcellus formation will be occurring simply were not designed for either the weight or the volume of traffic transported to and from shale gas wells. Even in Texas, where drilling thus far has been in comparatively much more urbanized areas, specifically Denton, Tarrant counties, roads and highways have suffered much greater rates of degradation than would have been the case ordinarily. In both Texas and Pennsylvania, roads and bridges are often posted with weight restrictions, to provide indications and warnings of at-risk infrastructure. Companies can often exceed the legal restrictions either by applying for variances or securing performance bonds, which require companies to perform or pay for maintenance resulting from their activity ("Road Bonding").

2.2.3.2 Recent Road News

Pennsylvania has already seen substantial drilling activity in some rural areas. In fact, the Pennsylvania Department of Transportation (PennDOT) revoked permits for Chesapeake Energy's use of four state-maintained highways in northwest Pennsylvania ("Gas Business"). According to the regulations specific to the roads in question, the weight limit is capped at 10 tons. However, Chesapeake was granted a variance to move the necessary equipment and water into areas like Bradford County for hydrofracking shale wells. The variance stipulated that Chesapeake "proactively monitor[s] pavement conditions and immediately begin[s] repairs as needed to keep the road safe." According to its website, PennDot suspended Chesapeake’s usage permits due to the company’s failure to deal with severe roadway damage caused by its drilling activities.

Under the terms of the use permit, Chesapeake is to "proactively monitor pavement conditions and immediately begin repairs as needed to keep the road safe," the website announcement says. Despite the normal10-ton weight restriction, Chesapeake’s permits allowed the movement of considerably heavier vehicles and equipment on the roads in question so long as the company would be responsible for repairs to damages caused by their the additional traffic and weight loads.

2.2.3.3 Conclusion

Based on the available literature, it is clear that heavy trucks, carrying even heavier equipment, travelling on roads not designed to accommodate such heavy loads, and doing so many hundreds, or even thousands of times, leads inexorably to dramatic degradation of local road and highway infrastructure. This damage can be mitigated, but remediation and repair can be expensive. This is particularly true if the culprits shirk responsibilities for maintenance, or are never required to do so in the first place. While the damage to roads and highways associated with well development cannot be fully avoided, it absolutely can be minimized and repaired after the fact. Thus, road and highway infrastructure damage represents a critical associated negative externality of shale gas development that state and local policies can effectively address.

2.2.3.4 Water Usage

While it would be beyond the scope of this work to develop a stand-alone set of water usage estimates, much of the data needed, and the projection estimates from those data were designed and compiled in a 2007 study by Bene and Harden, under the name

Northern Trinity/Woodbine Aquifer Groundwater Availability Model: Assessment of Groundwater Use in the Northern Trinity Aquifer Due to Urban Growth and Barnett Shale Development. The report projected water usage in the Barnett based on projected growth models, none of which proved accurate compared to how development actually proceeded in the Barnett.[53] Unfortunately, this particular study deviates greatly from what actually occurred. However, this study provides considerable insight into how to establish reliable projections for water usage.

While the Bene and Harden study focused narrowly on the Northern Trinity and Woodbine Aquifers in the Dallas-Fort Worth area, the study specifically addressed both urban growth and Barnett shale development. This aligns well with addressing the microeconomic developments arising from water usage.[54]

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[53] Undoubtedly, much of the stunting of development in the Barnett, and thus the deviation from the models within the Bene and Harden report was the direct result of the economic downturn that began in 2008. While it is difficult to estimate the degree to which Barnett development suffered as a result of the economic recession, it is clear that a large portion of the decline in activity was due to the collapse in natural gas prices that was precipitated by the economic downturn. The collapse in natural gas prices greatly reduced the profitability of drilling new wells in the Barnett. In fact, the price of natural gas still has not recovered to pre-recession levels. As such, Barnett development likewise has not recovered to pre-recession levels. Thus, the Bene and Harden models failed to accurately predict Barnett development mostly because their models did not presupposed or predict exogenous price shocks like the subprime collapse.

[54] The Bene and Harden study based its research upon a groundwater availability model originally developed for the northern Trinity Aquifer and combined with data gathered by surveys designed and mailed by Freese and Nichols, Inc., which mailed the surveys to 123 water entities in their study area. The survey "inquired about water use since 2000, particularly focusing on water use in the Trinity aquifer. Forty-seven percent of the recipients participated in the survey…. The information provided by these entities helped establish the historical water use in the Trinity aquifer. … Some entities have made agreements to purchase surface water and plan to decrease their dependence on the Trinity aquifer. Others plan to continue using the Trinity aquifer as their sole water supply" (Bene et al. 1-1).

These projections fell into three separate categories, all based upon proposed well completions in the Barnett, and were labeled “low,” “medium,” and “high” to coincide with the projections based upon historical well completion numbers in the Barnett. In comparing the projections to actual data from 2008 onward, the projections deviated significantly from actual well completion. The low projection, for example, overstates the expected number of 2010 well completions by 432 new wells spud, or 40.4%.

The study projections were based upon the market conditions at the time of the study, which preceded the global economic collapse and the subsequent drop in natural gas prices. Barnett shale development, like all hydrocarbon development, is heavily dependent upon market prices. Production may not make good economic or financial sense if the cost of the end product is not high enough. In this case, few in the financial markets warned against the possibility of such an exogenous shock to the overall energy markets.

In addition, the volumes of water this study used understated the volumes of water being used to drill and frack the Barnett wells. When compared to the Chesapeake Energy estimates, the numbers used in the Bene and Harden study understate the volume of water needed per well by as much an 1.2 million gallons of water.[55]

It should also be noted that re-fracking of the first horizontal wells from the early 2000s has commenced (“U.S. Shale Gas”). This in essence amounts to repeating the same process that originally occurred to develop the well. The major difference is that the well

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[55] Chesapeake Energy has published numerous estimates for water usage in both the Barnett play and the Marcellus. The estimates referred to here are the ones that deal specifically to the Barnett.

itself has already been drilled, and the process focuses on opening new fractures in the source rock below. Refracking was not accounted for in the Bene and Harden study.

According to this study, "[d]uring a drought, there is increased pressure on water supplies to support increased irrigation and other demands. While conservation measures can eventually reduce overall consumption, increased groundwater use can initially occur during dry weather conditions" (Bene and Harden 27). Thus, it is important to recognize that drought conditions may not reduce industrial usage until after substantial stores of groundwater have already been used.

According to a 2007 study, all water in Texas that "flows in creeks, rivers, and bays is owned and managed by the State" (Nicot and Potter). Accordingly, any person or concern withdrawing surface water "for mining, construction, and oil or gas activities must obtain a water rights permit from the Texas Commission on Environmental Quality (TCEQ)." It is unclear if this regulation is uniformly enforced. Based on the discrepancy between the numbers reported to the TCEQ and the figures released by various drilling companies, the potential for underreporting exists. This has been bolstered by anecdotal evidence by officials in the Barnett area.[56] This water source change – from one easily trackable, to many that are not – would explain why the numbers available officially and the numbers released in press releases by companies differ greatly.

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[56] According to Denton, TX officials, many of the companies who had been purchasing water from the City of Denton secured arrangements with private landowners to use their collected surface water, in order to reduce the costs associated with purchasing water from a municipality (Nickerson).

A number of recycling companies have become active in these shale plays.[57] However, these recycling technologies had not been put into action on any large scale in the Barnett until recently – from 2008 onward. Hence, these technologies will alter the overall projections of water usage moving forward – particularly in plays that have not yet experienced the larger portion of development – but they have not heavily affected water usage in the Barnett play to date. Nicot and Potter went on to conclude that, while the recycling technology is proven and available, the practice of recycling would take time to before it would cause a significant effect on water usage.

As was the case in Texas for the Barnett development, such considerable volumes of water necessary for developing the Marcellus play could well play havoc with groundwater supplies, particularly under conditions of drought or areas with over-taxed water systems. This was the case in Texas recently when Texas experienced sustained periods of drought.[58]

In addition to this, drilling companies will be required to truck in much of the water necessary for this development. While Pennsylvania, unlike Texas, enjoys substantial and reliable water sources, the magnitude of the Marcellus shale development

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[57] Some recycling companies capable of addressing the issues specific to shale gas development include companies like Ecosphere Technologies or Fountain Quail. Fountain Quail did not become active in the Barnett play until 2005, at which point it began with a single field unit and tested its evaporation method south of the town of Decatur, in Wise County. The first was initiated in Wise County, south of Decatur, by Fountain Quail Water Management in 2005. DTE Gas Resources also became active in the Barnett in 2005. Ecosphere did not become active in the Barnett play until 2008. There are other companies also active in the Barnett ("RIGZONE," "Water recycling").

[58] Texas is currently experiencing its worst drought in decades. U.S. Drought Monitor, a non-profit effort at the University of Nebraska at Lincoln, categorizes the current drought conditions in Texas as "exceptional," their worst designation (McFerron and Campbell, "US Drought Monitor").

may make that a moot point simply because of the sheer enormity of the volumes of water involved and the increased chance of groundwater contamination that such extensive development will entail. Much of the water to be used in the Marcellus will simply be collected from rivers, streams, ponds, and wells. Due to the urban nature of the Barnett play, where operator companies could purchase water from municipalities as well as take surface water or drill their own wells, and the rural nature of the Marcellus play, the simple fact of the matter is that there will likely be substantially greater amounts of traffic resulting from Marcellus development, as opposed to Barnett development. Moreover, that traffic will likely do more damage because of the comparably less-well-engineered roads in Pennsylvania's rural areas.

2.3 A Political Crossroads: What Path Should Pennsylvania Take?

2.3.1 Severance Taxes vs. Natural Resource Funds

As mentioned previously, severance taxes can function in many ways like NRFs. This is mostly related to how the money ends up being implemented from a policy standpoint. However, severance taxes differ on a major, if overlooked point that makes all the difference in the world: separate management.

Just as in the financial world, commingling of funds generally never leads to positive results. By allowing severance proceeds to reside in the general fund, there are simply too many incentives – political, economic, financial – for policymakers to pass up using that revenue for general purposes. This leads to the possibility of the government in question falling into the trap of allowing those revenues to feed into the resource curse negative feedback loop: expansion of services during boom times, deficit/debt –funded spending in lean times. This negative feedback loop results in no long-term benefit from the windfall of resource extraction royalties, due to disincentives to save general fund revenues and the natural business cycles that lead to commodity price volatility.

NRFs provide a number of protections from these pitfalls. First, by sequestering the funds, there is no comingling of funds, and therefore no completely surreptitious way to spend those funds. Second, if established properly, the NRF provides a responsive and responsible administration of those revenues in a politically fair and palatable manner. While an NRF is only as effective as its charter and initial (or even subsequent) tasking, it provides considerably more protection and oversight over the use of royalty revenues.

Chapter 3: Methodology

3.1 Rationale for the Research and Current Status of the Problem

The ongoing search for relatively inexpensive energy sources has led to the development of new technologies, enabling access to previously unusable resources. The recent boom in shale gas development has only happened because of these new technologies coupled with older technologies, making shale gas an economically viable energy option. However, shale gas plays, like some other unconventional hydrocarbon plays, exhibit comparably steep extraction curves. The nature of these plays lends itself to initially higher rates of extraction with subsequent precipitous production collapses.

Such sharp changes potentially create or exacerbate boom-bust cycles and their attendant economic problems. Shale gas development is also a young and poorly understood process, the environmental and geological effects of which have scarcely been considered. However, much research is being conducted to determine precisely what the effects may be. A recent example of this push to develop without waiting to understand the consequences is the micro-tremor problem in the Fayetteville shale formation, which seem to be directly linked to fracking activity in the region (Robertson).

This research has a specific focus on the budgetary issues that may arise as a result of shale gas development – specifically, the economic impact of shale gas drilling as measured through road infrastructure and water management.

3.2 Statement of the research objectives

The present research paper has the objective to investigate the need for Pennsylvania to establish a state gas fund in anticipation of budgetary and microeconomic complications arising from the development of the Marcellus shale formation.

3.3 Research Question

The research question for this thesis is as follows:

Does the development of natural gas shale reserves create the conditions for the development of negative economic externalities?

If so, can these attendant economic problems be effectively managed and mitigated by the creation of a natural resource fund (or “gas fund”)?

3.4 Research design

3.4.1 Barnett Shale Formation

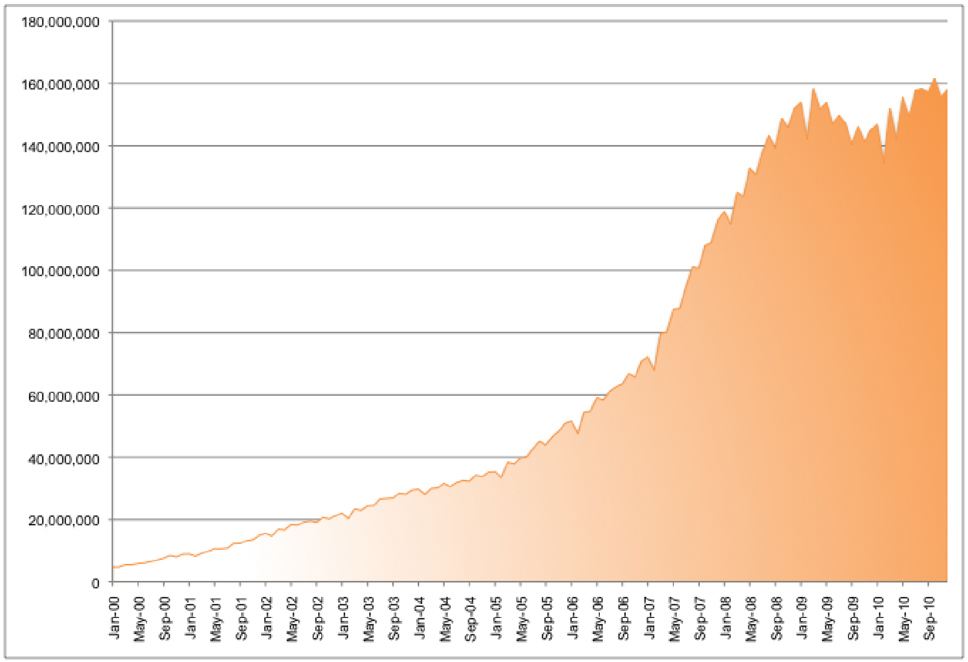
Data for this research is focused primarily on the Barnett shale formation in Texas. The Barnett development is the most mature development of a shale gas field in the world. Most of the current techniques in the field of natural gas extraction were developed there. The Barnett play has been steadily and seriously developed since 1999. The Barnett can provide meaningful guidance in terms of what one might expect moving forward with new plays. At minimum, it can provide a case against which new production and development may be compared. The Barnett should provide a good baseline test case upon which to construct a model for future unconventional hydrocarbon plays.

While other shale gas plays in the United States (including the Marcellus, the Haynesville, and the Fayetteville) have seen considerable interest and development, the Barnett remains the most well-established with the largest amount of readily available data. Moreover, the Barnett has become the basis for projections in the Marcellus formation. The precedent has been established by Engelder and Lash (volume projections) and Considine (economic benefits) (Engelder and Lash, Considine et al. "An Emerging Giant").

Where applicable, data analysis is confined to the years 2000 and 2007. Where data is not readily available annually, or showed a standard curve/rate of growth through that time period, the beginning and end dates were used exclusively. Pre-2000 data is not relevant because using directional drilling and hydraulic fracturing together, which makes shale gas exploration economically viable, was not used before 2000. Starting with 2000 data enables the research to view the Barnett shale play in its infancy. The year 2007 was chosen as a stopping point because the 2008 housing collapse and economic recession had the potential to skew data for reasons completely unrelated to shale gas development.

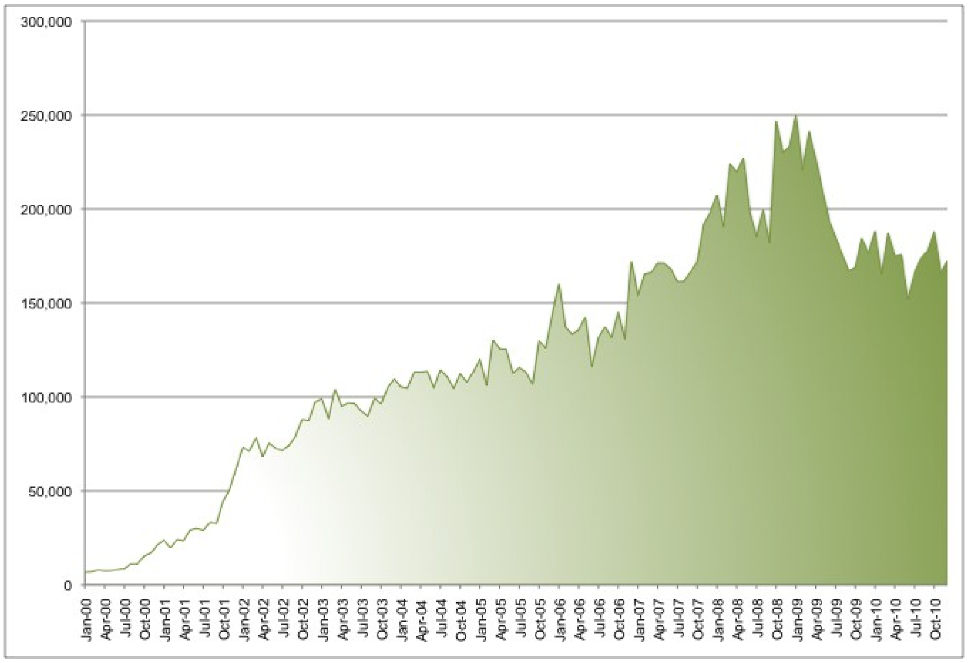
In addition, the curve of the extraction volume in the Barnett becomes unpredictable after 2007. Because this research aims to focus on issues relevant to Marcellus formation start-up, the changing curve would only serve to confuse the issues at hand. Figures 4-5 depict the growth of active wells and extraction volume (gas and condensates) from 2000-2010, illustrating this issue.

Figure 4. Total Monthly Extracted Gas Volume (MCF) in Barnett Play 2000-2010



Source: Texas Railroad Commission

Figure 5. Total Monthly Extracted Condensate Volume (BBL) in Barnett Play 2000-2010



Source: Texas Railroad Commission

3.4.2 County breakdown

Initial population data is viewed for all variables at the county level. The Barnett shale formation is centered on four counties (referred to as the "core" counties – Denton, Johnson, Tarrant, and Wise counties).[59] All data tables in this research will include these four counties. In addition, initial tables in the transportation section will reference the seventeen counties adjacent to them (referred to as the "peripheral" counties – Bosque, Clay, Comanche, Cooke, Coryell, Dallas, Eastland, Ellis, Erath, Hamilton, Hill, Hood, Jack, Montague, Palo Pinto, Parker, and Somervell counties) as well as other counties in the state with a population of 40,000 and above (a total of 68 of the state's 254 counties).[60] Table 5 lists the counties and their 2000 and 2007 populations.

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[59] Between January 2000 and December 2010, the core counties had 12,387/15,644 shale gas wells in the state (79.2%) and 7,697,860,795 MCF/8,672,219,628 MCF production in the state (88.8%).

[60] The 40,000 cutoff point is rounded down from the 2000 population of Wise County (45,094). These 68 counties had a 2000 population total of 17,733,620/20,190,519 in the state (87.8%).

Table 5. Study Counties (Barnett Shale Play)

County	2000	2007	County	2000	2007
Anderson	52,291	56,202	Kerr	44,021	47,235
Angelina	78,573	82,424	Lamar	45,965	49,787
Bastrop	53,191	71,726	Liberty	68,687	77,176
Bell	228,127	269,073	Lubbock	229,931	253,601
Bexar	1,379,147	1,550,160	Maverick	47,756	52,162
Bowie	82,047	93,286	Mc Lennan	204,609	224,167
Brazoria	236,372	286,773	Midland	117,755	124,383
Brazos	143,533	167,228	Montgomery	295,263	399,941
Cameron	324,127	389,571	Nacogdoches	58,929	62,867
Cherokee	45,334	48,320	Navarro	43,549	48,715
Collin	472,109	696,306	Nueces	311,732	318,651
Comal	78,444	102,032	Orange	86,578	84,026
Coryell	73,916	76,007	Parker	85,410	106,811
Dallas	2,073,301	2,340,063	Polk	44,081	46,349
Denton	**413,087**	**590,120**	Potter	109,657	121,375
Ector	122,948	127,212	Randall	101,033	111,427
Ellis	110,097	139,104	Rockwall	43,197	69,658
El Paso	698,787	743,319	Rusk	45,800	48,093
Fort Bend	356,555	487,047	San Patricio	71,363	69,477
Galveston	249,898	282,126	Smith	169,263	194,792
Grayson	104,762	118,438	Starr	53,081	62,432
Gregg	113,683	117,743	**Tarrant**	**1,399,470**	**1,667,306**
Guadalupe	82,523	111,122	Taylor	127,391	128,115
Hardin	47,426	50,419	Tom Green	104,462	103,123
Harris	3,275,630	3,830,130	Travis	734,764	928,037
Harrison	62,658	63,715	Val Verde	44,074	47,362
Hays	93,293	133,913	Van Zandt	44,355	51,827
Henderson	69,642	79,331	Victoria	83,395	86,334
Hidalgo	542,528	708,235	Walker	56,905	64,026
Hunt	69,920	83,050	Webb	198,399	234,498
Jefferson	244,812	245,922	Wharton	41,335	42,252
Jim Wells	40,227	41,102	Wichita	127,495	130,521
Johnson	**121,480**	**150,981**	Williamson	240,905	349,982
Kaufman	67,448	93,807	**Wise**	**45,094**	**56,495**

Source: Texas Department of Transportation

3.4.3 Independent variables

The goal of the research question is to determine whether, how, and by how much the hydrocarbon industry development affects the local and state economies in which it occurs. While the possible ways to address and measure such changes are manifold, this study focuses specifically upon budgetary and microeconomic effects stemming from shale gas development – specifically road infrastructure damage and the fair market value of water usage. It is exceedingly clear from the available literature that extractive industries create substantial externalities – both positive and negative – for the states, regions, and localities in which development occurs. Therefore, the intent here is to determine a reliable means of calculating those effects. Data for the number of wells used, the volume of gas extracted, and volume of condensates extracted is used to determine how the size of the play affects immediate localities.[61] These three variables are the primary independent variables in this research, the combination of which will provide the tools necessary to create both descriptive and predictive models.[62] In theory, production on a small scale will have a comparably smaller effect upon the surrounding area than production on a larger scale, which would both be necessitated and indicated by larger per well volumes. The larger the scale of the production, the more complicated the policy and budgetary implications will be. In this way, the number of wells drilled and the volume extracted provide a solid basis for comparison, and a credible representation of level of development.

3.4.4 Dependent variables

Shale gas has a quick but expensive initial development period, and exhibits steep depletion curves. This compressed timeline for play development lends itself to what amounts to faster, more capital-intensive development for localities (McFarland, Nuttall). While a given state as a whole may not necessarily experience budgetary complications on a large scale, localities often experience micro boom/bust cycles. The potential for many pockets of extreme deindustrialization, increased service load, and higher traffic

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[61] For example, higher volume extracted per well drilled generally indicates greater wellpad size, overall displacement, and a higher number of workers operating the site.

[62] Data on wells and production volume is obtained from the Texas Railroad Commission (TRRC). Texas requires reporting of extractable volume at the wellhead for both oil and natural gas extraction to the TRRC. This is the primary and most accurate data source for well numbers and production volume in Texas.

should be addressed before local areas are negatively impacted. Since this work is limited to considering two specific types of negative externalities, the variables will reflect this focus. The variables considered, then, include projected infrastructure costs and expenses as well as projected water usage and estimated fair market values of water used.

3.4.4.1 Infrastructure

One of the most identifiable effects hydrocarbon development can have on a given locality is the increase in traffic on roads and highways. For shale gas, the problem is amplified because of the transportation of clean water to well sites for the fracking process, and removal of flowback water for disposal. Unless pipeline infrastructure exists for these purposes, tanker trucks must be used. Due to the realities of both shale gas development and basic capital infrastructure in the U.S. – truncated development cycles when compared to oil, leading to relatively short and punctuated local development, as well as a lack of dedicated water or gas transmission pipelines as is the case in most areas of shale gas development in the U.S. – high numbers of truckloads is an accurate assumption with regard to shale gas development.

Road infrastructure will likely be one of the greatest immediate and ongoing attendant costs associated with shale gas development. It will also be the most readily observable and measurable, and could potentially affect the greatest number of people. Operator companies have taken to avoiding state and county roads in both Texas and Pennsylvania wherever possible. The resultant pressure on local roads is magnified because non-state and non-county roads must be maintained with local tax receipts. Local roads also do not generally meet the same standards for usage or tonnage that state or county roads must meet. Because of these factors, infrastructure degradation can be more extreme on already lower-quality roads.

By keeping to local roads, operator companies shift the maintenance burden to localities, which have proportionally less power than the state as a whole. With smaller constituencies and fewer observers in general, the negative externality of infrastructure degradation gets less direct attention and therefore less funding than such a problem might ordinarily warrant.

Despite these potential problems, Texas has developed long-standing relationships with oil and gas developers at both the state and local levels. Well-established laws and regulations are also present. Moreover, the overall quality of roads in Texas is high.[63] This is due in part to the relatively road-friendly climate in Texas, where temperatures rarely dip far below freezing. General maintenance necessary for repairing climate induced damage is minimal compared to northern states. Despite Texas' proportionally higher taxpayer burdens for high-quality roads, this also indicates both a willingness on the part of Texas policymakers to prioritize highway expenditures and an uncanny responsiveness to concerns arising from complications in highway transportation.

Data chosen for highway costs comes from the Texas Department of Transportation's District and County Statistics (DISCOS) reports, which provides data relating to roads, highways, bridges, and aviation ("DISCOS"). Data relating to number of registered vehicles – public monies spent on new construction, repair, and maintenance

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[63] According to reason.org's 19th Annual Report on the Performance of State Highway Systems (2010), Texas ranks 13th overall, indicating proportionally better overall outcomes, despite low marks in total disbursements (36th) and urban interstate congestion (37th).

of existing roads – is used for this research. The transportation maintenance budget must, by its very nature, be a lagging indicator of problems. That being said, it is an indicator only in direct proportion to how responsive the government in question happens to be to such problems, and how strong the imbedded constituency for such an amenity happens to be. In Texas' case, the state legislature seems to be highly responsive, and the built-in constituency likewise seems rather sensitive to worsening highway conditions. It remains to be seen how effective this variable will prove to be when applying it to other shale gas developments.

While the number of cases for each group, particularly the core group, limit greatly the degree to which any inferential techniques can be brought to bear, one can still get a rather clear picture of what has happened in these areas by looking at the numbers. The lack of inferential statistical analysis limits the degree to which one can establish a multivariate causal model, but the observations themselves can provide considerable insight into how extractive industries – and shale gas in particular – will pan out elsewhere.

The study of infrastructure costs in Texas requires considering actual dollars spent on maintenance. Unfortunately, Texas funds its infrastructure at a number of levels. While the state provides funding for state highways via federal money and state taxes, the counties are responsible for maintaining county roads, and towns and cities are, by and large, required to service the roads that fall within their jurisdiction. The Texas Department of Transportation (TXDOT) collects data on funding, but it does not include local funding, or even all county funding. Despite this, the DISCOS data provided by the TXDOT remains the best alternative for data on highway maintenance, as the data is collected uniformly across the state. While data on county and city maintenance does exist, there are many formats and measures that do not necessarily make for easy comparisons. The DISCOS data, while incomplete with respect to localities and some county funding, is the best and most uniform data available.

The best way to address this issue is to compare actual maintenance costs, measured in dollars per lane mile. TXDOT breaks out total maintenance costs, as well as provides total lane miles by county. Therefore, in order to determine cost per lane mile, the computation is a simple matter of dividing total dollars spent by the number of miles of state-funded highway found within each county.

This variable will ideally prove that shale gas development has a substantially greater overall effect on local and state budgets than has been presumed up to this point. It should serve as an indicator for policymakers to take greater care in considering more broadly the attendant effects of such large-scale, but relatively one-dimensional, economic activities.

3.4.4.2 Water

Fracking can use either surface water or groundwater as a source. Currently, it is estimated that companies use groundwater approximately 60% of the time, with county-wide averages ranging from about 45% to 90% (Bene et al.). While the majority of the water used in the Barnett shale development came from groundwater sources (Byrd), a substantial amount still was either purchased from municipalities or taken from surface water sources (Nickerson).

Despite substantially more monitoring of water usage in the Barnett by the Texas Water Development Board (TWDB) and other semi-public entities – particularly important considering both how much water is used in fracking and the extent to which droughts afflict Texas water supplies – the situation in the Barnett still does not present an optimal solution. There are literally thousands of water providers in Texas. There remains no central storehouse of data for water usage, unlike the Texas Railroad Commission's (RRC) tracking of gas production. This lack of centralization of statistics regarding water usage has made the data gathering challenging.

Therefore, using the projections adapted from the Bene, et al. study, one can estimate microeconomic effects, using the municipal rates available from Tarrant and Denton counties.[64] Once these basic guidelines and estimations have been devised, this methodology will then be projected for the Marcellus play.

Since the Bene, et al. projections fail to provide an accurate estimate of water volume in regard to drilling, a new model must be devised. Currently a number of companies can effectively recycle flowback water to a degree that some can be reused, up to 80% of captured flowback water ("Welcome to Fountain Quail"). If approximately 70% of the water used to frack a horizontally drilled well returns, and 80% of that water can be reused, the asymptotic function approaches zero after only 8 cycles. The result of this is an increase of 127% efficiency in terms of the amount of water that can be used. In other words, if 100 gallons are used initially, it equals a total of approximately 227 gallons of water that can be used for fracking, or an additional 127 gallons over and above the original 100 gallons ("Water Use").

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[64] The intent here is to determine fair market value for the water. By employing the pricing structure used by the biggest municipal water providers in the area, it provides relatively accurate estimates of what private users should be paying for water usage.

The nature of both water use projections and drilling – with newer and better technologies altering the operational calculus almost constantly – complicate the task of determining the impact of Barnett Shale production on groundwater. Water used for fracking can be found practically anywhere, from groundwater, surface water, municipal sources, or recycling previously used water. Still, transporting water in from elsewhere – even if the distances are relatively small – can become very expensive very quickly. Therefore, developing and instituting better recycling technologies is a high priority for operating companies as a means of both minimizing costs for water usage further and providing a better public façade for the water usage issue in general. Indeed, the additional demand pressure that drilling imposes upon the supply of water will likely become a high priority for localities as well.

The Barnett and the Marcellus formations will require different amounts of water in order to frack. While a Marcellus well averages about 3 million gallons per frack,[65] a well in the Barnett averages about 4.5 million gallons per frack ("Barnett Shale Production"). This is because Marcellus shale tends to run shallower than Barnett shale, and deeper plays require greater amounts of water to frack a well. Also, the rules and regulations regarding drilling in Pennsylvania require fewer frack stages in the Marcellus, thus requiring less water.[66] A typical Marcellus well usually requires completions that involve multi-stage fracks with more than three stages per well ("US Shale Gas").

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[65] According to a 2008 study done by John Harper of the Pennsylvania Bureau of Topographic and Geologic Survey, Department of Conservation and Natural Resources, "a horizontal well completion might use more than 3 million gallons" of water for a successful single-stage frac job.

[66] In wells with multiple frac stages, each successive frac stage generally requires more water than the previous stage, due to the length or depth of the well being drilled, as well

However, some observers[67] anticipate larger total volumes of water in the Marcellus. Even if the Marcellus wells tend to require less water for each well, there will likely be more wells drilled in the Marcellus. The Marcellus is both richer and larger than the Barnett play, and is more dense. Because of the Marcellus source rock's comparatively higher organic content,[68] the projections for total gas extractions anticipate considerably higher gas extraction volumes, also likely to require more water for extraction.

It should be noted here that, even with the projections for potential extractable gas from the Marcellus, there are a bevy of estimates for the number of wells needed to fully exploit the resource.[69] However, this model is designed to provide broad estimates. As with the other models established in the work, it is very sensitive to the inputs of the variables. In this case, using the lifetime per-well estimate from the Barnett very well may not be accurate, because the Marcellus seems to be producing considerably more gas, under considerably more pressure, than the Barnett wells. Therefore, going forward, this model will necessarily need to be tweaked in order to provide ongoing accurate projections as technology and more data become available.

This model is meant to provide new insights into ways in which one can more accurately and fairly determine the damage to infrastructure being caused by drilling

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as the additional pressure from previous fracs dissipating into previously fracked shale rock.

[67] Even Chesapeake, one of the major operator companies in the Marcellus, is estimating very high water volumes. Most recently, the company released a fact sheet that used the volume of 5.6 million gallons as an average volume of water needed to successfully drill and hydrofrac Marcellus shale gas wells ("Water Use Fact Sheet").

[68] Typically, higher organic content in shale results in higher potential extractable hydrocarbon volume. This is generally the case with both oil and natural gas shale.

[69] Moors' estimate or 110,000-220,000 wells, for example.

activities. While this author feels that it is a rather accurate assessment of the problem, there will always be room for improvement to the model. The model itself is an abstraction, an attempt to aggregate the damage overall, rather than to determine point damage to specific roads and highways at specific times. Moreover, this research is meant to be the beginning of much more future research, rather than a terminus, and it should be received with that in mind.

There will undoubtedly be criticism of this work, and not undeservedly. Some of the core assumptions, particularly the traffic equivalency measure, need to be updated so as to provide a more timely and recent assessment of road damage based on the newest data and construction techniques. That being said, no updated research has been found after 1962, and therefore represents the weakest portion of this model.

However, it should be noted that while the study may or may not prove to provide the most recent and accurate assessments of damage equivalencies, that is simply a matter of altering inputs to the model, rather than undermining the model's design itself. Once new engineering research has been performed, this model should become even more robust, and its results even more valuable to policymakers.

Furthermore, it should also be noted that the entire intent behind this research is to provide actionable analysis for policymakers, or at very least a framework for analysis within which policymakers can make more informed and fairer decisions regarding policy.

Chapter 4: Results

4.1 Roads

4.1.1 Introduction

Road infrastructure damage is probably the most visible initial effect of shale gas development, particularly if the development is rural in nature. While any casual bystander can witness the comings and goings of oversized loads trucking in water, sand, and equipment, the clearly observable residual effects of this development tend to manifest as broken pavement, cracked or bent bridge trusses, or even completely destroyed roadbeds. Even in urban settings, where the roads and highways tend to be newer – and often better built and maintained due to the higher traffic patterns – the amount of damage can be substantial. The following sections describe and explain the road infrastructure results from analyzing development from the Barnett, as well as projections based upon the best estimates for usage in the Marcellus.

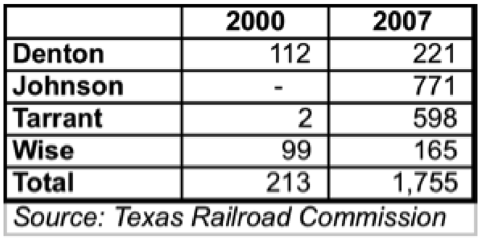
4.1.2 Barnett

4.1.2.1 Annual well completions

Table 6 shows the number of wells completed in the four core counties of the Barnett formation during the two years examined for this research. No substantial amount of development occurred in any of the counties in 2000 relative to what occurred later; therefore, that year functions as the baseline. The development that had occurred prior to that point in time consisted almost solely of vertical wells, since this period predates the convergence of horizontal drilling and hydraulic fracturing. Hence, the tremendous amounts of water, sand, chemicals, and equipment needed to hydraulically fracture and directionally drill those wells had not yet factored in to the overall road infrastructure maintenance costs. Since Texas has been a major producer of petroleum and natural gas for a number of decades prior to the advent of shale gas development, the state had already factored into the road maintenance calculations much, if not all, of the projected costs associated with conventional hydrocarbon production.

Production in Johnson County, the last of the four "core" counties in the Barnett formation, had not yet begun in 2000 despite the fact that development had begun in the other three core counties. There is a substantial difference in the amount of development taking place in 2007 as compared to 2000. The year 2007 represents the peak year of well completions for the Barnett formation. Of note is that Johnson County's production began in 2003, and that county is considerably less populated than Denton and Tarrant counties. Hence, Johnson County provides a situation of extremely high development compressed in a comparably short period of time, which provides us with an opportunity to observe an extremely high rate of development over time compared to the other core counties. These data were the basis for determining overall activity in the core Barnett counties, as the entire model stems from determining a per well measure of activity.

Table 6. Annual Well Completions (Barnett)



	2000	2007
Denton	112	221
Johnson	-	771
Tarrant	2	598
Wise	99	165
Total	213	1,755

Source: Texas Railroad Commission

Note that as of the end of 2007 Johnson County represents almost 44% – 43.93% to be precise – of all shale gas development within the core counties.

4.1.2.2 Truck trip calculations

Table 7 shows an estimate of the number of trips necessary to drill and frack the wells in each core county during the subject years. The calculations are based on the assumption that each well requires an average of 3 million gallons of water. Even at an average of only 3 million gallons of water per well and at relatively low levels of development, the result in terms of increased traffic can be enormous, and potentially enough to simply overwhelm the infrastructure of various localities. These trucks, often weighing 20 times as much as regular cars, can damage roads to a much greater degree than their weight would suggest. Because the weight of the trucks often exceeds the weight limits of these roads and highways by orders of magnitude, the stress these trucks place upon roadways affects the underlying infrastructure more than merely looking at truck trips and mileage. Even for purposes of this research, conservative estimates were employed so as not to potentially overstate the effects associated with shale gas development. The following calculations are based on research by the Highway Research Board ("Advocates"), which determined that a single 40-ton (80,000 pound) tractor-trailer truck imposes as much damage on highways as 9,600 average-sized passenger cars.

Table 7. Number of Drilling Truck Trips (3 million gallon estimate)

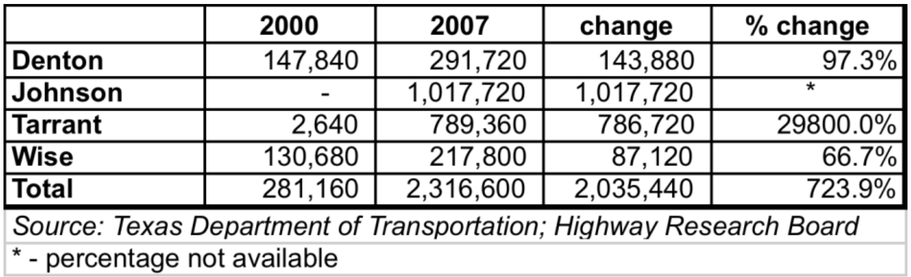
	2000	2007	change	% change
Denton	101,360	200,005	98,645	97.3%
Johnson	-	697,755	697,755	*
Tarrant	1,810	541,190	539,380	29800.0%
Wise	89,595	149,325	59,730	66.7%
Total	192,765	1,588,275	1,395,510	723.9%

Source: Texas Department of Transportation; Highway Research Board

* - percentage not available

Table 8 illustrates the number of truck trips based on an average of 4.5 million gallons of water (the high estimate). Like the estimates in the table above, these numbers are based on research by the Highway Research Board and further illustrate the issues evident at an average of 3 million gallons per well. Together, these numbers provide a baseline range to consider for calculating overall infrastructural damage, particularly when looking at other more water- and equipment-intensive shale plays.

Table 8. Number of Drilling Truck Trips (4.5 million gallon estimate)



	2000	2007	change	% change
Denton	147,840	291,720	143,880	97.3%
Johnson	-	1,017,720	1,017,720	*
Tarrant	2,640	789,360	786,720	29800.0%
Wise	130,680	217,800	87,120	66.7%
Total	281,160	2,316,600	2,035,440	723.9%

Source: Texas Department of Transportation; Highway Research Board

* - percentage not available

4.1.2.3 Equivalent vehicle numbers

Table 9 below establishes equivalency figures for the two average water volumes, which provides the likely damage range. The figures in Table 9 were calculated by multiplying the estimated number of truck trips required to develop the wells sunk in the respective years (at 3 million and 4.5 million gallons of water respectively) by the number of estimated equivalent cars, and then divided by 365. Since the product of the estimated number of trips and the passenger car equivalency factor would seem to potentially overstate the damage incurred by the roads as a result of shale gas development, that product must be tempered by the fact that the trucks in question do not represent permanent new daily vehicles, but rather only single discrete trips. Therefore, in order to temper the calculation of the numerator product, this study assumes that the truck trips in question represent a single day’s travel. By dividing the numerator product by the number of days in the year, a more conservative estimate of additional traffic that shale gas development imposes on the local infrastructure is determined.

Table 9. Equivalent Vehicle Numbers (3 and 4.5 million gallon estimates)

	3 million gallon estimate		*4.5 million gallon estimate*	
	2000	**2007**	**2000**	**2007**
Denton	2,665,907	5,260,405	3,888,395	7,672,636
Johnson	-	18,351,912	-	26,767,430
Tarrant	47,605	14,234,038	69,436	20,761,249
Wise	2,356,471	3,927,452	3,437,063	5,728,438
Total	5,069,984	41,773,808	7,394,893	60,929,753

Source: Texas Department of Transportation; Highway Research Board

4.1.2.4 Drilling adjusted vehicle numbers

Tables 10-11 show the numbers calculated by adding the estimated additional traffic resulting from shale gas development to the data provided by TXDOT related to registered vehicles. Both the equivalent registered vehicles (from a traffic standpoint) and the additional estimated damage to local and state infrastructure are shown. These calculations provide us with an estimated range of the unfunded damage incurred by roads.

Table 10. Unfunded Damage (3 million gallon estimates)

	2000	**2007**	**Unfunded Damage 2000**	**Unfunded Damage 2007**
Denton	3,007,306	5,758,845	$ 92,614,889.35	$ 353,474,731.88
Johnson	114,775	18,498,456	$ -	$ 5,791,308,079.55
Tarrant	1,283,521	15,725,648	$ 872,680.10	$ 663,437,476.34
Wise	2,412,165	4,002,723	$ 211,930,519.39	$ 629,694,157.21
Total	6,817,768	43,985,673	$ 131,591,876.19	$ 3,046,893,880.82

Source: Texas Department of Transportation; Highway Research Board

Table 11. Unfunded Damage (4.5 million gallon estimates)

	2000	2007	Unfunded Damage 2000	Unfunded Damage 2007
Denton	4,229,794	7,672,636	$146,945,066.35	$ 515,565,354.79
Johnson	114,775	26,767,430	$ 5,838,453.05	$8,446,990,790.06
Tarrant	1,305,352	20,761,249	$ 23,929,060.17	$ 967,665,711.35
Wise	3,492,757	5,728,438	$314,122,997.85	$ 918,448,936.48
Total	9,142,677	60,929,753	$237,299,002.06	$4,444,088,312.35

Source: Texas Department of Transportation; Highway Research Board

4.1.2.5 Costs, overfunding, and unfunded damage estimates

From the data collected and analyzed on the 68 total counties of this study, it became clear that the state of Texas has attempted to fund – at least partially – the repair of infrastructure damage inflicted upon state highways by shale gas development. Since this data made it clear that the core counties had received, on average, more funding for road and highway repair from the state, even after controlling for population and increase in registered vehicles, the remaining analysis will focus only on the four core counties of Denton, Johnson, Tarrant, and Wise.

The goal of this research is to provide a clear model for policymakers to employ in order to accurately assess compensatory taxation or appropriate user fees. By far, the great majority of unconventional gas extraction in Texas has occurred in the four core counties. By focusing on these four counties only, the results will be extremely clear and more easily applicable for policymakers. Therefore, a fairer value for repair can be determined by calculating a more accurate level of damage done and for which taxation had not compensated the state and localities.

What should also be noted is that most trucking traffic for shale gas development, by its very nature, occurs on local highways and roads. While state highways are often built to higher engineering standards than local highways, that greater robustness and capability to withstand more and heavier traffic means little if the greatest volumes of traffic occur on other roads and highways. This is one of the primary reasons the city of Denton opted to assess local usage fees for drilling in the Barnett.[70] Yet, despite these additional fees, the money collected goes toward only the thoroughfares in Denton city proper. According to Keith Gabbard, Street and Drainage Superintendent of the City of Denton, Denton has collected approximately $1.5 million in usage fees (Gabbard). While that money has gone quite a ways toward mitigating the damage from Barnett drilling within Denton city limits, it by no means paid for it all, particularly in light of the price increases for oil-related products like asphalt since the fee was made policy.

It should also be noted that the following data does not include the specific local data on infrastructure spending in Texas. The focus on this research is to address state budgetary policy concerns. While local infrastructure expenditures will likely affect the following calculations to some minor degree, the intent is to show the magnitude of difference between what is being spent currently and what should be spent. Therefore, while the county data are likely available, the overall effect on the discrepancy between county and local expenditures on the one hand, and actual under-funded and un-funded damage on the other is likely to be rather small, as indicated by the amount of money collected by way of usage fees (and the fact that these usage fees have proven insufficient) by the City of Denton.

Table 12 shows the number of vehicles registered in each of the four core counties, as well as data called Drilling-Adjusted Vehicle Numbers (DAVN). The DAVN refer to the equivalent car traffic represented by drilling. The DAVN is calculated by first

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[70] Denton was chosen as the main locality of research for two primary reasons. First, Denton experienced the earliest and greatest amount of development in the Barnett until very recently, and second, the accessibility of personnel and their willingness to discuss the topic of Barnett shale development made the research task a much less tedious one.

multiplying the estimated passenger car equivalent, 9,600[71], by the average number of truck trips necessary to drill and frack the number of wells spud in a given year. Since that calculation does not accurately model truck behavior as it occurs in the field – each discrete truck trip should be counted as a single trip on a single day, rather than multiplied out over an entire year's worth of traffic – the product must be altered to more accurately represent the actual behavior of trucks. Otherwise, the product could potentially vastly overstate the level of activity in question. This model uses the number of days in a single year as an adjustment factor. The product of the estimated passenger car equivalent and the average number of truck trips necessary to drill and frack the number of wells spud in a given year is divided by 365. The resulting number gives a more conservative, and likely more accurate, estimation of the actual traffic.

While the average well in the Barnett has required approximately 3 million gallons of water to drill and frack, it makes sense to calculate the damage based upon that volume of water – and consequently, the number of heavy trucks necessary to move that amount of water. However, as with all other types of hydrocarbon development, the easiest and cheapest to develop areas generally get developed first, so as to enable faster realization of profit for a given drilling company. One should expect that, moving forward, the amount of water necessary to drill and frack new wells will increase. This will entail greater volumes of water and equipment, and consequently greater damage to infrastructure.

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[71] This constant was developed by the GAO, and published in a 1962 report ("EXCESSIVE").

Table 12. Drilling-Adjusted Vehicle Numbers

		Vehicles Registered	Drilling-Adjusted Vehicle Numbers (3M gallon estimate)	Drilling-Adjusted Vehicle Numbers (4.5M gallon estimate)
Denton	2000	341,399	3,007,306	4,229,794
	2007	498,440	5,758,845	7,672,636
Johnson	2000	114,775	114,775	114,775
	2007	146,544	18,498,456	26,767,430
Tarrant	2000	1,235,916	1,283,521	1,305,352
	2007	1,491,610	15,725,648	20,761,249
Wise	2000	55,694	2,412,165	3,492,757
	2007	75,271	4,002,723	5,728,438
Total	2000	1,747,784	6,817,768	9,142,677
	2007	2,211,865	43,985,673	60,929,753

Table 12 shows that the DAVN is much larger than the number of vehicles registered in the respective counties. Each of the counties above shows at least ten-fold increases in equivalent traffic directly resulting from drilling. One would expect that, accordingly, infrastructure damage would likewise increase by at least ten-fold. The funding necessary to remediate that damage, just to maintain the *status quo*, must also increase accordingly.

Table 13 below shows a number of separate pieces of data from which the necessary calculations to build this model are developed. The calculations include per car infrastructure spending for the four core counties, the change in per car expenditures between 2000 and 2007, and the unfunded damage per water volume estimate. This data is necessary for understanding the calculations for Table 14.

Table 13. Infrastructure Costs, Overfunding, and Unfunded Damage Estimates[72]

	Denton	*Johnson*	*Tarrant*	*Wise*	*Total*
2000 Infrastructure Cost Per Car	$ 34.74	$ 50.87	$ 18.33	$ 89.94	$ 25.96
2000 (adjusted for inflation)	$ 41.83	$ 61.25	$ 22.07	$ 108.28	$ 31.25
2007 Infrastructure Cost Per Car	$ 67.20	$ 315.57	$ 46.61	$ 160.33	$ 72.94
change (adjusted for inflation)	$ 25.37	$ 254.32	$ 24.54	$ 52.05	$ 41.69
% change (adjusted for inflation)	61%	415%	111%	48%	133%
2007 Vehicles	498,440	146,544	1,491,610	75,271	2,211,865
Overfunding Total	$ 12,644,325.70	$ 37,269,632.72	$ 36,601,262.10	$ 3,917,785.96	$ 90,433,006.49
2007 Unfunded Damage (3M gallon estimate)	$ 353,474,731.88	$ 5,791,308,079.55	$663,437,476.34	$ 629,694,157.21	$ 7,437,914,444.98
2007 Unfunded Damage (4.5M gallon estimate)	$ 515,565,354.79	$ 8,446,990,790.06	$ 967,665,711.35	$ 918,448,936.48	$ 10,848,670,792.68
Revised 2007 Unfunded Damage (3M gallon estimate)	$ 340,830,406.18	$ 5,754,038,446.82	$626,836,214.24	$ 625,776,371.25	$ 7,347,481,438.49
Revised 2007 Unfunded Damage (4.5M gallon estimate)	$ 502,921,029.09	$ 8,409,721,157.33	$931,064,449.24	$ 914,531,150.53	$ 10,758,237,786.19

Source: Texas Department of Transportation; Highway Research Board

The Overfunding Total represents the amount of money in dollars by which the State of Texas increased infrastructure maintenance expenditures between 2000 and 2007, over the cost of inflation. This number is used to determine the amount by which the actual infrastructure expenditures mitigate the Unfunded Damage calculation, which shows the raw calculation of infrastructure damage, not controlled for actual infrastructure spending.

While one might expect infrastructure expenses to increase in accordance with the DAVN, that has not happened. As Table 13 clearly shows, infrastructure expenses increased dramatically across all core counties from 2000 to 2007, but the increase is not enough to maintain the roads as they were prior to drilling.

The Road Maintenance Costs (Actual) data were provided by TXDOT. The Necessary Road Maintenance Costs are the sum of the actual road maintenance costs and the Revised Unfunded Damage caused by drilling activity. The unfunded damage is calculated by first determining the infrastructure maintenance cost per vehicle, then

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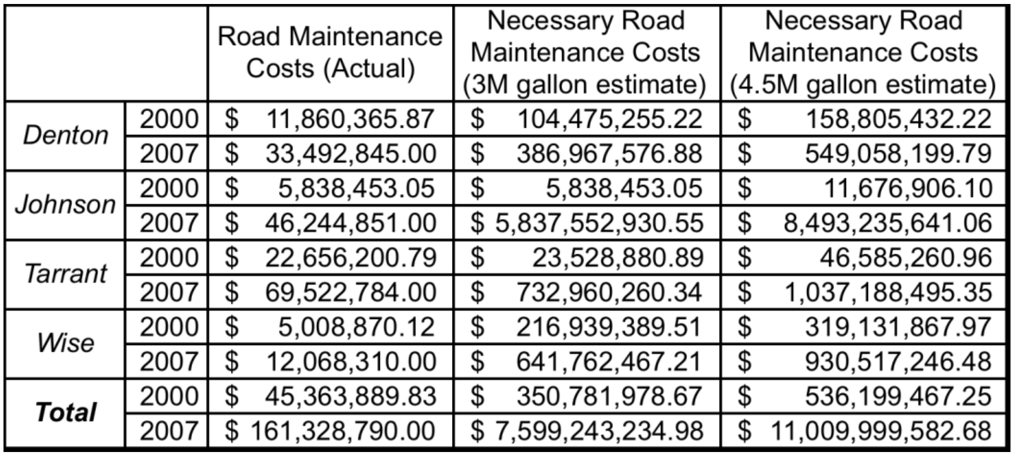
[72] Costs were adjusted for inflation – all calculations are made in 2007 dollars for comparison purposes.

multiplying that dollar value by the DAVN, and then adjusted based upon the actual maintenance funding data. The Revised 2007 Unfunded Damage is calculated by subtracting the Overfunding Total from the Unrevised, i.e., raw, Unfunded Damage, as shown in the table above.

The product of that calculation provides a more complete assessment of the damage imposed by the large trucks involved in drilling on the state and local highways.

Table 14. Road Maintenance Costs (Actual and Estimated)



		Road Maintenance Costs (Actual)	Necessary Road Maintenance Costs (3M gallon estimate)	Necessary Road Maintenance Costs (4.5M gallon estimate)
Denton	2000	$ 11,860,365.87	$ 104,475,255.22	$ 158,805,432.22
	2007	$ 33,492,845.00	$ 386,967,576.88	$ 549,058,199.79
Johnson	2000	$ 5,838,453.05	$ 5,838,453.05	$ 11,676,906.10
	2007	$ 46,244,851.00	$ 5,837,552,930.55	$ 8,493,235,641.06
Tarrant	2000	$ 22,656,200.79	$ 23,528,880.89	$ 46,585,260.96
	2007	$ 69,522,784.00	$ 732,960,260.34	$ 1,037,188,495.35
Wise	2000	$ 5,008,870.12	$ 216,939,389.51	$ 319,131,867.97
	2007	$ 12,068,310.00	$ 641,762,467.21	$ 930,517,246.48
Total	2000	$ 45,363,889.83	$ 350,781,978.67	$ 536,199,467.25
	2007	$ 161,328,790.00	$ 7,599,243,234.98	$ 11,009,999,582.68

While this model vastly simplifies the process of determining the precise amounts of damage being done, the point is that it provides a much more accurate picture of the magnitude of the policy concerns involved in shale gas drilling and should be considered a starting point for the accurate assessment of infrastructure costs associated with shale gas development. This model does not attempt to provide a model that addresses certain other complicating factors, such as increased damage to infrastructure resulting from previously unrepaired damage. As with many problems, unaddressed damage tends to compound over time, particularly as the stress in question does not abate. This is most certainly the case with road and highway maintenance. Oftentimes, such problems must be assessed on a case-by-case basis. This fact should not be presumed to undermine the baseline calculations above. Rather, those problems would serve to likely increase the necessary funding for damage mitigation, since the tendency has been to allow infrastructure improvements and repair to go lacking.

For example, asphalt and concrete are designed with cracks and joints respectively, to provide both room for expansion and improved performance under impact loading. As these cracks and joints degrade over time and due to increased load-bearing, they lose their strength, resulting in faster degradation. Also, higher vehicle speeds and larger loads make the impact and load-bearing burden imposed upon these roads greater, particularly at the asphalt cracks and concrete joints.

It should be noted that a number of factors will affect the accuracy of the calculations within this study. All calculations in this analysis assume that trucks carry standard loads according to weight; hence, there is an assumption of 80,000 pounds per load. However, numerous studies have found that many of the loads the trucks in question carry are overloaded in order to reduce transportation costs ("Institute"). Overloading will cause considerably more severe damage overall to highways and roads, as damage incurred by highways and roads tends to increase exponentially once the safe operating parameters have been breached. It is very difficult to obtain accurate overloading information from drilling companies, as that information is not necessarily considered public record and the release of those data are not in the financial or political best interests of drilling companies. For future studies, more reliable data should be used to increase accuracy of analysis results. New data should become more easily accessible as time goes on.

4.1.3 Marcellus

4.1.3.1 Annual well completions

For the Marcellus formation calculations, the same process used to determine infrastructure costs in the Barnett is being used to determine a baseline and subsequently a projection of necessary infrastructure costs based on projected well completions. Table 15 shows the number of wells completed in the twenty-five counties with active well completions in the Marcellus formation during 2010.[73] Counties at that point in time with the highest number of well completions include Washington (221), Greene (194), Bradford (169), Tioga (128), and Susquehanna (109).

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[73] Because the Marcellus formation has only recently seen substantial development, it is not yet possible to compare production over time with any relevant results.

Table 15. Annual Well Completions (Marcellus)

Allegheny	3
Armstrong	41
Bradford	169
Butler	33
Cambria	1
Cameron	4
Centre	12
Clarion	6
Clearfield	19
Clinton	23
Elk	6
Fayette	87
Forest	1
Greene	194
Indiana	16
Jefferson	4
Lycoming	37
McKean	8
Potter	20
Somerset	4
Susquehanna	109
Tioga	128
Warren	2
Washington	221
Westmoreland	75

Source: Pennsylvania Department of Environmental Protection

4.1.3.2 Truck trip calculations

Table 16 develops an estimate of the number of trips necessary to drill and frack the wells in each active county, with values calculated at both 3 million and 4.5 million gallon estimates (low and high water volume estimates). This provides the range of truck trips due to drilling estimated in 2010.

Table 16. Number of Drilling Truck Trips (3 and 4.5 million gallon estimates)

	3 million	4.5 million
Allegheny	2,715	3,960
Armstrong	37,105	54,120
Bradford	152,945	223,080
Butler	29,865	43,560
Cambria	905	1,320
Cameron	3,620	5,280
Centre	10,860	15,840
Clarion	5,430	7,920
Clearfield	17,195	25,080
Clinton	20,815	30,360
Elk	5,430	7,920
Fayette	78,735	114,840
Forest	905	1,320
Greene	175,570	256,080
Indiana	14,480	21,120
Jefferson	3,620	5,280
Lycoming	33,485	48,840
McKean	7,240	10,560
Potter	18,100	26,400
Somerset	3,620	5,280
Susquehanna	98,645	143,880
Tioga	115,840	168,960
Warren	1,810	2,640
Washington	200,005	291,720
Westmoreland	67,875	99,000

Source: Pennsylvania Department of Environmental Protection; Highway Research Board

4.1.3.3 Equivalent vehicle numbers

Table 17 establishes vehicle equivalency figures for the two average water volumes. The figures in Table 17 were calculated by multiplying the estimated number of trips required to develop the wells sunk in the respective years (at 3 and 4.5 million gallons of water respectively) by the number of estimated equivalent cars, and then divided by 365, as in the Barnett calculations above.

Table 17. Equivalent Vehicle Numbers (3 and 4.5 million gallon estimates)

	3 million	4.5 million
Allegheny	71,408	104,153
Armstrong	975,912	1,423,430
Bradford	4,022,663	5,867,310
Butler	785,490	1,145,688
Cambria	23,803	34,718
Cameron	95,211	138,871
Centre	285,633	416,614
Clarion	142,816	208,307
Clearfield	452,252	659,638
Clinton	547,463	798,510
Elk	142,816	208,307
Fayette	2,070,838	3,020,449
Forest	23,803	34,718
Greene	4,617,732	6,735,255
Indiana	380,844	555,485
Jefferson	95,211	138,871
Lycoming	880,701	1,284,559
McKean	190,422	277,742
Potter	476,055	694,356
Somerset	95,211	138,871
Susquehanna	2,594,499	3,784,241
Tioga	3,046,751	4,443,879
Warren	47,605	69,436
Washington	5,260,405	7,672,636
Westmoreland	1,785,205	2,603,836

Source: Pennsylvania Department of Environmental Protection; Highway Research Board

4.1.3.4 Drilling adjusted vehicle numbers

Table 18 shows the numbers calculated by adding the estimated additional traffic resulting from shale gas development to the data provided by PennDOT related to registered vehicles. Both the equivalent registered vehicles (from a traffic standpoint) and the additional estimated damage to local and state infrastructure are shown.

Table 18. Drilling-adjusted Vehicle Numbers and Unfunded Damage

	3 million		4.5 million	
	estimated vehicles	unfunded damage	estimated vehicles	unfunded damage
Allegheny	777,742	$ 6,201,198.11	810,487	$ 9,044,841.45
Armstrong	1,020,111	$ 263,024,805.84	1,467,629	$ 383,638,390.83
Bradford	4,058,862	$ 1,953,422,988.56	5,903,509	$ 2,849,191,541.33
Butler	926,385	$ 81,978,070.59	1,286,583	$ 119,570,224.51
Cambria	112,535	$ 5,327,606.19	123,450	$ 7,770,652.13
Cameron	98,228	$ 75,649,463.14	141,888	$ 110,339,548.44
Centre	356,496	$ 45,999,860.00	487,477	$ 67,093,718.45
Clarion	165,015	$ 70,740,662.82	230,506	$ 103,179,751.30
Clearfield	498,733	$ 127,621,954.15	706,119	$ 186,144,728.71
Clinton	568,397	$ 494,478,457.41	819,444	$ 721,228,247.27
Elk	162,755	$ 36,906,068.68	228,246	$ 53,829,846.03
Fayette	2,158,565	$ 384,545,207.26	3,108,176	$ 560,883,617.22
Forest	26,849	$ 19,347,963.92	37,764	$ 28,220,234.66
Greene	4,638,305	$ 2,178,430,262.97	6,755,828	$ 3,177,378,947.09
Indiana	429,133	$ 128,559,759.20	603,774	$ 187,512,576.95
Jefferson	121,699	$ 32,535,004.30	165,359	$ 47,454,370.92
Lycoming	952,034	$ 172,184,102.38	1,355,892	$ 251,141,453.19
McKean	212,988	$ 68,045,759.32	300,308	$ 99,249,063.31
Potter	485,353	$ 411,582,659.91	703,654	$ 600,319,459.75
Somerset	143,213	$ 29,669,067.14	186,873	$ 43,274,219.47
Susquehanna	2,620,116	$ 1,335,088,392.79	3,809,858	$ 1,947,311,246.94
Tioga	3,070,670	$ 1,376,385,488.10	4,467,798	$ 2,007,545,684.30
Warren	70,141	$ 17,644,808.85	91,972	$ 25,736,074.79
Washington	5,390,607	$ 1,192,170,029.74	7,802,838	$ 1,738,855,733.98
Westmoreland	2,010,952	$ 190,024,815.62	2,829,583	$ 277,163,266.98

Source: Pennsylvania Department of Environmental Protection; Pennsylvania Department of Transportation; Highway Research Board

4.1.3.5 Costs, overfunding, and unfunded damage estimates

Table 19 shows actual and estimated maintenance costs based on shale gas development in the Marcellus. Actual road maintenance cost data were provided by PennDOT. The necessary road maintenance costs are the sum of the actual road maintenance costs and unfunded damage caused by drilling activity. Unfunded damage is calculated by first determining the infrastructure maintenance cost per vehicle, then multiplying that value by the drilling-adjusted vehicle numbers, then further adjusted based on actual maintenance data. The product of that calculation provides a more complete assessment of the damage imposed by large trucks involved in drilling on state and local roads.

Table 19. Road Maintenance Costs (Actual and Estimated)

	Road Maintenance Costs (Actual)	Necessary Road Maintenance Costs	
		3 million	4.5 million
Allegheny	$ 61,339,116.40	$ 67,540,314.51	$ 70,383,957.85
Armstrong	$ 11,912,374.76	$ 274,937,180.60	$ 395,550,765.59
Bradford	$ 17,578,394.84	$ 1,971,001,383.40	$ 2,866,769,936.17
Butler	$ 14,704,571.94	$ 96,682,642.53	$ 134,274,796.45
Cambria	$ 19,860,283.23	$ 25,187,889.42	$ 27,630,935.36
Cameron	$ 2,397,144.54	$ 78,046,607.68	$ 112,736,692.98
Centre	$ 11,412,159.96	$ 57,412,019.96	$ 78,505,878.41
Clarion	$ 10,995,736.85	$ 81,736,399.67	$ 114,175,488.15
Clearfield	$ 13,116,570.70	$ 140,738,524.85	$ 199,261,299.41
Clinton	$ 18,907,965.96	$ 513,386,423.37	$ 740,136,213.23
Elk	$ 5,152,558.85	$ 42,058,627.53	$ 58,982,404.88
Fayette	$ 16,290,502.49	$ 400,835,709.75	$ 577,174,119.71
Forest	$ 2,475,929.19	$ 21,823,893.11	$ 30,696,163.85
Greene	$ 9,705,381.47	$ 2,188,135,644.44	$ 3,187,084,328.56
Indiana	$ 16,300,702.89	$ 144,860,462.09	$ 203,813,279.84
Jefferson	$ 9,051,344.55	$ 41,586,348.85	$ 56,505,715.47
Lycoming	$ 13,946,167.22	$ 186,130,269.60	$ 265,087,620.41
McKean	$ 8,063,780.80	$ 76,109,540.12	$ 107,312,844.11
Potter	$ 8,038,771.20	$ 419,621,431.11	$ 608,358,230.95
Somerset	$ 14,958,094.92	$ 44,627,162.06	$ 58,232,314.39
Susquehanna	$ 13,182,107.31	$ 1,348,270,500.10	$ 1,960,493,354.25
Tioga	$ 10,805,532.81	$ 1,387,191,020.91	$ 2,018,351,217.11
Warren	$ 8,352,891.66	$ 25,997,700.51	$ 34,088,966.45
Washington	$ 29,507,786.58	$ 1,221,677,816.32	$ 1,768,363,520.56
Westmoreland	$ 24,029,464.70	$ 214,054,280.32	$ 301,192,731.68

Source: Pennsylvania Department of Environmental Protection; Pennsylvania Department of Transportation; Highway Research Board

4.1.4 Comparison between Barnett and Marcellus (discussion)

It is clear from the above calculations that, while Texas has experienced considerably more infrastructure stress and damage than areas in Pennsylvania as a direct result of Barnett development, this is a temporary situation. As the Marcellus formation is further developed, the sheer volumes of *in situ* gas and the rural aspect of Marcellus development will lead directly to substantially more infrastructure damage – perhaps orders of magnitude more damage.

4.2 Water

4.2.1 Introduction

Shale gas drilling currently requires large volumes of water. However, despite the volume of water needed to produce gas from shale, even at peak activity, the process may only account for only between 1% and 3% of total water consumption in a given area. More telling is the comparison between the amount of water required for drilling and the vast volumes of water available for use. The best estimates available show that drilling usage does not necessarily produce a price effect (Nickerson). This lack of a price effect is mostly due to the way in which water is collected for use, either through the sinking of private wells or purchasing water from private property owners.

Even in drought conditions, as happens regularly in Texas, water usage for shale gas development does not necessarily overtly affect available volumes of water for other uses. However, the simple fact remains that water is being used, and in rather large quantities. More importantly, companies use much of that water without any manner of financial remuneration to the state or, in Pennsylvania's case, the Commonwealth. Oftentimes, even when companies compensate property owners for water usage, the price paid does not accurately reflect the economic value of water, and certainly does not factor the cost of remediation for potential spills or surface- or groundwater pollution. If for no other reason than for the potential for water pollution, some accounting of those facts should be taken. Moreover, since water is a communal resource, the potential for assigning real economic value should be considered.

4.2.2 Barnett

4.2.2.1 Number and type of well

Large amounts of water have been used to develop the Barnett shale formation. Estimates of water usage for all drilling and fracking in the Barnett are as high as 2% of the total water used in this region.[74] While such relatively small percentages of water do not sound like a serious threat to the Texas water supply and generally will not have a measureable effect upon the cost of water, the activities that require this water have the potential for destroying water sources – particularly if the activity is pursued without proper care – creating the potential for even percentage use as comparatively small as what shale gas development represents to be large enough to alter the overall cost of water.

As of September 2010, the month with the highest number of active wells on record, drilling and extraction companies have drilled a total of at least 14,891 wells, the vast majority of which were horizontally drilled and fracked. It is assumed that some previously active wells had fallen out of production, and other active wells may have been drilled vertically.[75] This should not greatly affect the total amounts of water necessary for development.

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[74] According to Chesapeake Energy, one of the primary companies operating in the Barnett and Marcellus shale formations, this data was acquired from a 2006 report from the Texas Water Board and a study conducted in 2007 by Dr. Peter Galusky of the environmental consulting firm, Texerra, and commissioned by the Gas Technology Institute ("Water Management").

[75] The hydraulic fracturing process generally requires many times more water to develop a well than the more traditional vertical technologies. Since the vast majority of wells drilled in the Barnett since 2000 have been horizontally drilled and hydrofracked, one can assume that substantially more water has been employed in the gas development than would have otherwise been the case had only vertical drilling technology been used.

4.2.2.2 Gas volume per well

As of December 2010, the average Barnett well has produced approximately 554,347.96 MCF of natural gas.[76] At that point in time, the Barnett represented the most actively fecund shale gas formation in the world. While this is due mostly to the Barnett formation representing one of the first shale gas developments in the world, the amount of natural gas being produced in the Barnett is not insignificant.

4.2.2.3 Water volume per well

Using an average volume of water of 4.5 million gallons per well,[77] the total amount of water necessary to perform the drilling in the Barnett formation total over 67 billion gallons (67,009,500,000).

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[76] This figure was calculated by dividing the total volume of natural gas extracted from active Barnett wells from January 2000 to Dec 2010 by the number of wells in production as of December 2010. As stated above, some wells certainly have fallen out of production, while others have come online during the period in question. The calculation above is simply a thumbnail calculation to determine overall per well production.

[77] According to a Chesapeake Energy factsheet, a typical shale gas well requires approximately 250,000 gallons of water for the actual drilling, and another 3.8 million gallons per well to perform the fracing process itself. Other companies may use more or less depending upon the specifics of their processes. Other sources within the industry put the estimated total water usage per well above 4.5 million gallons. It should also be noted that every additional frac stage requires additional water, and the amount of water necessary to perform a successful frac depends heavily upon on a number of factors, not least of which is the thickness of the formation itself, which varies by location. Typically, companies will drill in the easiest, most accessible, and cheapest locations first. Later, the more difficult, deeper, denser, less profitable areas will be developed. This also extends to water usage, as it typically requires more water as complications in drilling are added. According to another Chesapeake factsheet, the company claims to only use approximately 3.5 million gallons of water during the fracking process. A third factsheet (July 2010) claims that 5 million gallons of water are needed to drill and hydraulically fracture a shale gas well. The various numbers should, more than anything, illustrate the wide estimates provided by various private companies regarding their operations ("Barnett Water Use", "Water Management").

4.2.2.4 Water usage – municipal sources

Natural gas drilling companies often purchase water from municipal sources ("Water Use Fact Sheet"). While this does not necessarily affect the overall amount of water available underground, it can affect the total amount of water available from surface municipal sources, and can have an effect on the overall amount of water produced. When using municipal water sources, gas companies pay according to volume used. Due to price breaks made available for commercial/industrial users and at higher levels of consumption/use, gas companies do not typically pay for water at a rate commensurate with residential users. Still, there exists a distinct financial interest for gas companies to not pay for water usage if at all possible.

4.2.2.5 Flowback water disposal/containment

In the Barnett play, most flowback is removed from the well site by water tanker trucks. The flowback water is then typically injected into underground salt caverns that function as disposal wells.[78] Some water gets reused immediately or recycled for later use. According to the TRRC, the estimate for recoverable volume of injected frack water is approximately 70%, leaving around 30% in the ground ("Water Use in the Barnett"). According to Nicot and Potter, "[a]bout 30% of the injected water returns without too much of a quality decrease, whereas the remaining 40% is more degraded." These are average statistics and can vary greatly from well to well, based on the local characteristics of the formation as well as the standard operating procedures of a given producer.

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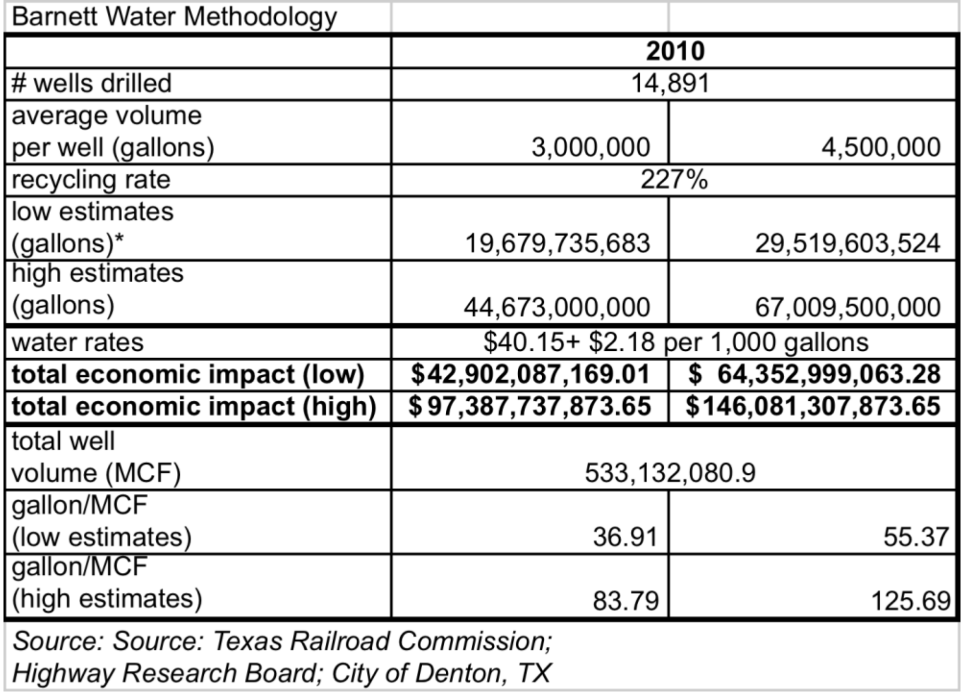
[78] According to Chesapeake Energy's website, the company injects unusable flowback water into a deep underground geological formation called the Ellenburger formation, a porous rock formation that rests beneath the Barnett formation ("Barnett Shale Production").

Table 20. Barnett Play Water Usage Estimates



Barnett Water Methodology		
	2010	
# wells drilled	14,891	
average volume per well (gallons)	3,000,000	4,500,000
recycling rate	227%	
low estimates (gallons)*	19,679,735,683	29,519,603,524
high estimates (gallons)	44,673,000,000	67,009,500,000
water rates	$40.15+ $2.18 per 1,000 gallons	
total economic impact (low)	**$42,902,087,169.01**	**$ 64,352,999,063.28**
total economic impact (high)	**$ 97,387,737,873.65**	**$146,081,307,873.65**
total well volume (MCF)	533,132,080.9	
gallon/MCF (low estimates)	36.91	55.37
gallon/MCF (high estimates)	83.79	125.69
Source: Source: Texas Railroad Commission; Highway Research Board; City of Denton, TX		

In Table 20, the estimates of water usage were based upon establishing a range (based on average water estimates provided by Chesapeake's public releases and the Tarrant County League of Women Voters). Recycling water (represented by the "recycling rate"[79] in the table) can have a significant impact on the total amount of water employed for shale gas development. As recycling becomes more efficient and cost-effective, it is expected that usage of recycled water will increase.

4.2.3 Marcellus

4.2.3.1 Number and type of well

Between 2008 and 2010, natural gas operators drilled a total of 2,349 Marcellus shale wells in Pennsylvania ("PermitDrilledmaps"). The vast majority of these wells were

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[79] The recycling factor is based upon official statistics released by Chesapeake.

drilled horizontally and therefore used substantially greater volumes of water than vertical or conventional wells.

4.2.3.2 Gas volume per well

As of December 2010, the average Marcellus well produced approximately 318,380.81 MCF. While there is a substantial difference between the gas per well produced in the Barnett and Marcellus plays, this can be explained by the length of time each respective play has been actively producing natural gas. While the Barnett has produced almost 250,000 MCF more per well, the play has also been active for eight more years. All indications in the Marcellus actually point to a much greater per-well extraction volume over the lifespan of each well when compared to the Barnett play.

4.2.3.3 Water volume per well

Using an average volume of water of 4.5 million gallons per well, the total amount of water necessary to perform the drilling in the Marcellus up to the end of 2010 totals over 10 billion gallons (10,570,500,000 gallons).

4.2.3.4 Water usage – municipal sources

To date, most water used for hydraulic fracturing in the Marcellus has been from surface sources. While some operators have obtained water from municipal sources, the nature of the Marcellus play itself – primarily rural, with many available surface water sources in Pennsylvania – operators can typically collect most of the water needed for the extraction process without using municipal sources.

4.2.3.5 Flowback water treatment

Since Pennsylvania has no underground formation equivalent to the salt caverns in the Barnett, flowback water is primarily hauled by tanker truck to sewage plants for treatment and discharge into rivers, or until recently to injection wells in northeastern Ohio. Both options have been documented as potentially threatening, because of issues with water contamination and microquakes.[80]

Table 21. Marcellus Play Water Usage Estimates.

	2010	
# wells drilled	2,349	
average volume per well (gallons)	3,000,000	4,500,000
recycling rate	227%	
low estimates (gallons)*	3,104,405,286	4,656,607,930
high estimates (gallons)	7,047,000,000	10,570,500,000
water rates	$4,501.14 + $7.26 per 1,000 gallons	
total economic impact (low)	**$22,542,640,166.46**	**$ 33,811,631,355.89**
total economic impact (high)	**$ 51,171,793,177.86**	**$ 76,752,403,177.86**
total well volume (MCF)	533,132,080.9	
gallon/MCF (low estimates)	5.82	8.73
gallon/MCF (high estimates)	13.22	19.83

Source: Pennsylvania Department of Environmental Protection; Highway Research Board; PWSA

4.2.4 Comparison between Barnett and Marcellus (volume)

As of December 31st, 2010, a total of 533,132,080.9 MCF[81] had been extracted from the Marcellus formation. By comparing this data to the Barnett data, the Marcellus' first two years is on par with the initial years of Barnett production. In May 2000, total Barnett production stood at 200,106,145 MCF, with a monthly production of 5,864,695

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[80] The New York Times reported extensively on the concerns of radioactivity in drinking water and the inability of sewage plants that accept drilling waste for treatment to test and properly treat flowback water. Pennsylvania is also the “only state that has allowed drillers to discharge much of their waste through sewage treatment plants into rivers” (Urbina).

[81] The DEP data, amounting to releases by 55 of 73 operating companies currently active in the Marcellus, provided no unit of measurement for the volume. However, assuming the data provided adheres to the industry standard, MCF, the data make sense.

MCF. Production within the Barnett shale formation began back in 1993, at which time the only production came from vertical wells.

It is more appropriate to look at data from the point at which companies had developed more advanced techniques for shale gas extraction. Considering extraction volume data from January 2000 onward, the point at which the Barnett reached the level of extraction rates comparable to the Marcellus is November 2001. At this point the monthly extraction in the Barnett had reached 13,520,365 MCF, from 1266 active wells.

4.2.5 Comparison between Barnett and Marcellus (Active wells)

As of September 2010, a total of 2,349 wells have been drilled (or spud) in the Marcellus, 1,454 of which have been active, with a total of 533,132,080.9 MCF gas extracted ("Marcellus Shale Production"). Based on the estimate of the volume of water needed to frack a well in the Marcellus[82], approximately 10.57 billion gallons of water should have already been used, in some capacity. This estimated water volume does not account for water that has been treated or cleaned for reuse. The number of wells drilled so far represents approximately 10% (9.764%) of the number of Barnett wells that are currently operating, which stands at 14,891 at its peak in September 2010.

Assuming the Marcellus experiences identical well development activity, one would expect volumes approaching the numbers discussed above as the total gross amount of water to be used.

The numbers above do not tell the entire story. When the Barnett was producing at the level of the Marcellus, there were approximately 76 inactive wells in Barnett as of November 2001, out of a total of 1246. That leaves 1174 active wells, or 5.77% of

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[82] Based on using 4.5 million gallons per well.

Barnett wells being essentially either inactive or not ready for full-time production. By comparison, at the same point in the Marcellus, 1454 wells have been spud, but only 872 wells reported activity, and 240 of those reporting zero production. While the well numbers happen to be comparable, the active wells are not. Thus, while the number of wells spud may be 1454, the actual number with any real extraction is 632, or 43.5% of the wells.

4.2.6 Comparison between Barnett and Marcellus (Gas volume)

Since the average Marcellus well will require between 3 and 4.5 million gallons to perform a successful frack, and if the number of wells only meets the number of wells drilled in the Barnett, the estimated volume of water may be as high as 44,673,000,000 gallons, or slightly more than 44 billion gallons. While this estimate will likely be on the low end, such a high volume of water may have dramatic effects upon localities.

The above numbers provide a vastly different perspective on production and water usage. Therefore, while the per well production average in the Barnett at the comparable volume was 170,448.16 MCF, the total per well production average for active Marcellus wells is much higher, at 318,281.62 MCF. Therefore, the average Marcellus well looks to be producing at close to twice the volume that the Barnett wells are producing.

As it stands currently – as of the 2010 release of drilling activity – the Marcellus seems to be using not just less water per well, but is producing considerably more gas per well and per gallon of water used.[83] In the Barnett, for comparable volumes,

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[83] This is probably due, in large part, to recycling and – more importantly – refracking in the Barnett. In the Marcellus formation, little refracking has been performed since it is

approximately 5,607,000 gallons of water were used. That equates to around 37.88 MCF of natural gas produced per gallon of water used. This estimate is arrived at by dividing the total gas volume produced by the product of active wells and average water usage per frack job in the Barnett. For the Marcellus, the numbers diverge greatly. Using the same equation, the result is 106.1 MCF per gallon of water used.

Undoubtedly, these proportions may change. The differences between the Marcellus and Barnett production could be a function of the effects of newer and better technology. However, it is clear that the Marcellus formation looks to be a considerably richer play.

4.2.7 Water cost projections

Table 22 projects the estimated water costs in the Marcellus – Pennsylvania only – based upon the current market water rates charged by Pittsburgh Water and Sewer Authority (PWSA)[84] for industrial usage. It should be noted that Pittsburgh charges less for industrial uses of water than for either residential or commercial uses. According to PWSA rates, there is a minimum charge for metering for anything above 548,000 gallons, $4,501.14 ("Pittsburgh Water and Sewer Authority"). While drilling companies in the Marcellus have generally refrained from using municipal water sources (because Pennsylvania has an abundance of surface water sources), this calculation determines the market value of the water being used, regardless of sourcing. For all volumes above 548,000 gallons, the rate, as seen in the table below, is $7.26 per thousand gallons.

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such a relatively new play. The Barnett, by comparison, is a mature play, the production of which having already peaked.

[84] PWSA rates were used for illustration purposes only. Rate information was readily available and it was assumed that the largest population center in the portion of the state affected by the Marcellus formation would provide a reasonable estimate of the market costs of water.

This projection uses the estimated average of 4.5 million gallons of water to frack each Marcellus well, plus the 500,000 gallons needed to drill each well, in order to determine the projected cost per well. This projection also includes cost estimates based on various recycling percentages of the overall water usage. With technology in this area improving over the next few years, one should presume that companies would seek to recycle as much water as possible, particularly if there is some monetary cost attached to the initial water extraction.

If the companies already drilling in the Marcellus were to pay for the water extraction estimated by this model, the potential for producing offsetting monies for related externality costs could be considerable. As shown in Table 22, the cost for water per well ranges from $18,585.57 (50% recycling) to $37,171.14 (no recycling). By multiplying the number of wells that have been drilled by the various per-well water costs at the various recycling rates, the unpaid compensation for water used for drilling and fracking through December 2010 ranges from $43,657,503.93 (50% recycling) to $87,315,007.86 (no recycling).[85] Imposing market costs upon water usage would presumably create a financial incentive for both improving the fracking process (using less water overall), and improving the recycling process (pushing for more efficient and more effective processes).

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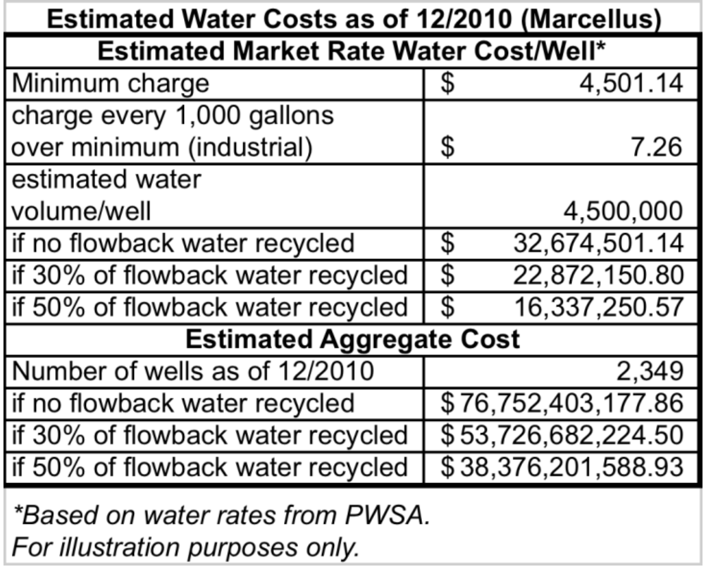
[85] These calculations are in current dollars (not adjusted for inflation).

Table 22. Estimated water costs

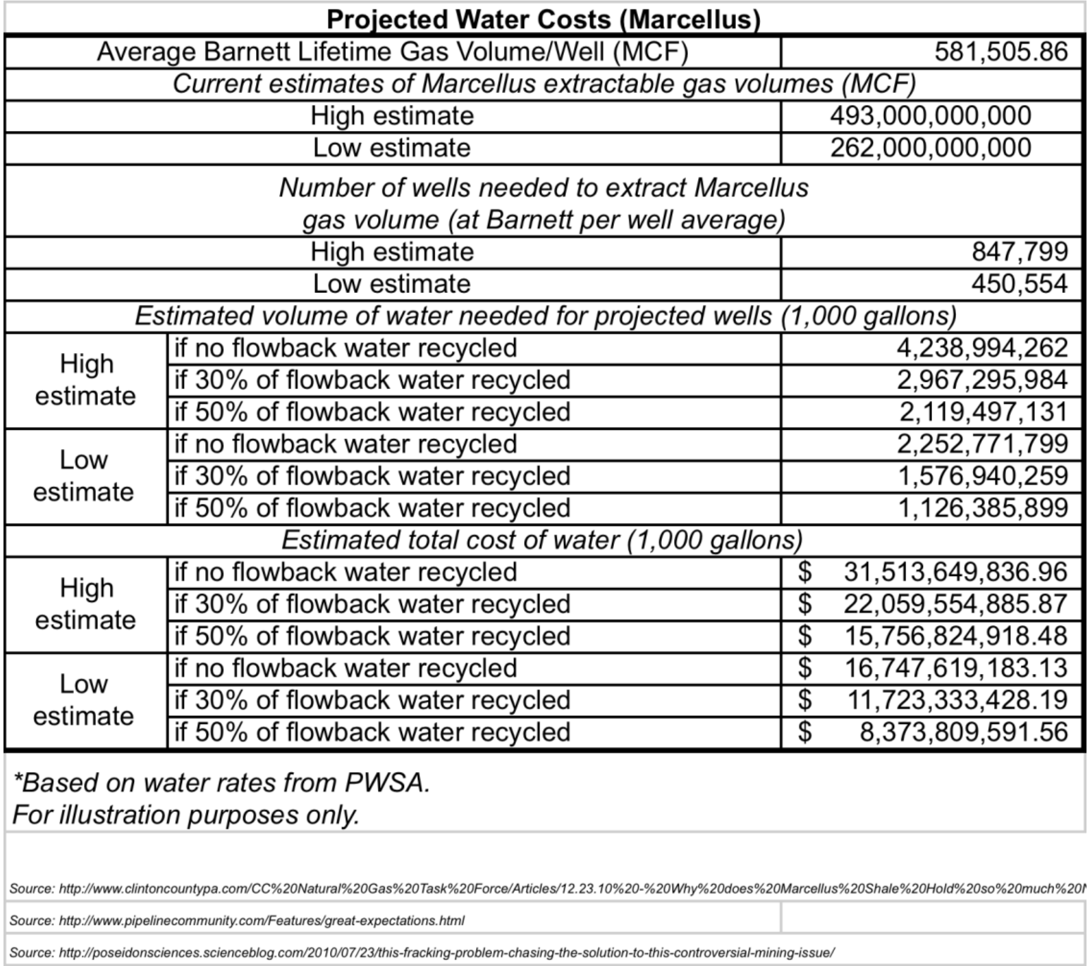


Estimated Water Costs as of 12/2010 (Marcellus)	
Estimated Market Rate Water Cost/Well*	
Minimum charge	$ 4,501.14
charge every 1,000 gallons over minimum (industrial)	$ 7.26
estimated water volume/well	4,500,000
if no flowback water recycled	$ 32,674,501.14
if 30% of flowback water recycled	$ 22,872,150.80
if 50% of flowback water recycled	$ 16,337,250.57
Estimated Aggregate Cost	
Number of wells as of 12/2010	2,349
if no flowback water recycled	$ 76,752,403,177.86
if 30% of flowback water recycled	$ 53,726,682,224.50
if 50% of flowback water recycled	$ 38,376,201,588.93

**Based on water rates from PWSA.*
For illustration purposes only.

Table 23 projects water usage and costs for the entire Marcellus gas formation, based on previous experiences in the Barnett formation. According to the most recent projections for extractable gas volumes in the Marcellus, a range is given, labelled *High estimate* and *Low estimate*. The high estimate is based partially on the Engelder/Lash projection, upon which all of Considine's projections were based. The lower estimate is based on a number of other more conservative estimates. The final extractable volume likely will fall somewhere between these two numbers. While the range does not offer enough precision for longer term planning, the projections provide at least a starting point from which policymakers can further understand what the Commonwealth may be facing in the coming months and years.

Table 23. Projected Water Costs (Marcellus)



Projected Water Costs (Marcellus)

Average Barnett Lifetime Gas Volume/Well (MCF)		581,505.86
Current estimates of Marcellus extractable gas volumes (MCF)		
High estimate		493,000,000,000
Low estimate		262,000,000,000
Number of wells needed to extract Marcellus gas volume (at Barnett per well average)		
High estimate		847,799
Low estimate		450,554
Estimated volume of water needed for projected wells (1,000 gallons)		
High estimate	if no flowback water recycled	4,238,994,262
	if 30% of flowback water recycled	2,967,295,984
	if 50% of flowback water recycled	2,119,497,131
Low estimate	if no flowback water recycled	2,252,771,799
	if 30% of flowback water recycled	1,576,940,259
	if 50% of flowback water recycled	1,126,385,899
Estimated total cost of water (1,000 gallons)		
High estimate	if no flowback water recycled	$ 31,513,649,836.96
	if 30% of flowback water recycled	$ 22,059,554,885.87
	if 50% of flowback water recycled	$ 15,756,824,918.48
Low estimate	if no flowback water recycled	$ 16,747,619,183.13
	if 30% of flowback water recycled	$ 11,723,333,428.19
	if 50% of flowback water recycled	$ 8,373,809,591.56

**Based on water rates from PWSA.*
For illustration purposes only.

Source: http://www.clintoncountypa.com/CC%20Natural%20Gas%20Task%20Force/Articles/12.23.10%20-%20Why%20does%20Marcellus%20Shale%20Hold%20so%20much%20

Source: http://www.pipelinecommunity.com/Features/great-expectations.html

Source: http://poseidonsciences.scienceblog.com/2010/07/23/this-fracking-problem-chasing-the-solution-to-this-controversial-mining-issue/

Based on these projections for the number of wells necessary, and combining those estimates with the estimates with the amount of water necessary to drill and frack those wells, a range for the estimated volume of water needed to develop the entire Marcellus formation has been calculated. The projections again factor in recycling at both 30% and 50%. Therefore, based on these estimates, Pennsylvania can expect water usage to range from 1,126,385,899,000 (1.126 trillion) gallons to 4,238,994,262,000 (4.238 trillion) gallons.

Using the PWSA rate calculations from the table above, and combining those with the water usage estimates for the entire Marcellus within the state, the aggregated costs being carried by the Commonwealth that should require compensation in some form are calculated. There is a range, as with the above projections, based upon recycling rates, as well as with the high and low extraction volume estimates. The range is from $8,373,809,591,560.00 ($8.373 trillion) to $31,513,649,836,960.00 ($31.513 trillion), over the entire extraction life of the Marcellus formation within Pennsylvania. This sounds like a substantial amount of money, particularly if viewed as an up-front expense for drilling companies. Instead, however, it makes greater sense to consider these values over the life of the entire development of the Marcellus. In the worst case scenario – assuming it requires a total of 5 million gallons of water to drill and frack each well – the cost to a given drilling company will be $37,171.14 per well. According to some sources, it currently costs between $5.0 and $6.4 million to fully develop a well ("Marcellus Shale – Well Cost"). If these numbers are accurate, even in the worst-case scenario of no recycling, paying for water usage will only increase the cost per well by between 0.5808% and 0.7434%.

Chapter 5: Conclusions (Policy Recommendations):

5.1 Introduction

The importance of preventing serious problems associated with extractive industries in general, and shale gas development in particular, necessitates a change in policy moving forward. While the impediments may seem difficult to surmount in the current political environment, the current situation provides policymakers a unique opportunity to learn from the successes and failures of others: namely, Texas, Alaska, West Virginia, Norway, Azerbaijan, and Russia.

By forging a new path with a pragmatic set of policies that the Commonwealth can adapt from other states and nations, Pennsylvania can pre-emptively address many of the complications that will arise from shale gas development. This proactive stance will also establish a certain precedent for any future extractive industries.

It is also critical to recognize that Pennsylvania is a policy trailblazer in the realm of shale gas development. Pennsylvania lawmakers must work to establish clear, equitable, and functional policies to circumscribe shale gas development, both to accurately represent the needs of the Commonwealth and act as a model for other states.

These policy recommendations should not be misconstrued as anti-shale gas – shale gas can and should factor greatly into a comprehensive state and national energy plan. However, this discussion must include the potential negative externalities associated with shale gas development, and provide for adequate remediation and preventative measures.

5.2 Policy Recommendations

5.2.1 Issue

Pennsylvania has tremendous underground natural gas resources in the Marcellus shale formation (as well as the underlying Utica formation), the development of which will produce substantial policy complications for the Commonwealth of Pennsylvania. Those complications will include, but not be limited to: budgetary issues, particularly infrastructural degradation and water pollution remediation; and microeconomic effects, namely localized inflation, sectoral inflation.

Based on the experiences of other states and nations whose economies rely upon extractive industries, Pennsylvania will likely encounter numerous problems that require foresight and planning to mediate.

5.2.2 Policy Options

The most appropriate and effective way to address the complications arising from extractive industries is to consider the problem holistically. Each of the following policy recommendations is important to mitigate the associated problems, and will help to equalize the benefits in a more equitable manner. In addition, proactively addressing problems before they arise makes future problems easier to address, and will end up with less difficulty when dealing with them.[86]

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[86] Since we have already witnessed substantial problems in the Barnett – and even in the Marcellus, despite being a relatively new development – it makes good sense to address both past problems and future problems that can be predicted with almost perfect certainty.

5.2.2.1 Recommendation #1

The Commonwealth should establish and properly and sufficiently fund a shale gas fund modeled upon natural resource funds already in place in states and nations whose economic development is closely tied to or dependent upon extractive industries.

This is the most critical alteration to current policy. Such a fund will provide the public means to address both short- and long-term problems associated with shale gas development, as well as provide a template for dealing with future extractive industries.

Since the Dutch Disease/resource curse problems are both well-documented phenomena associated with extractive industries, it seems only prudent to address such problems proactively. There are many other associated externalities that are not currently addressed, yet present profound and sustained complications for citizens affected by gas drills. By creating a fund, the purpose of which is to directly mitigate these problems – be they budgetary or microeconomic in nature – the Commonwealth can then remove these problems from the political arena, making the subsequent identification of such problems primarily bureaucratic.

Moreover, since it is clear that the user fees assessed by Pennsylvania upon drilling operators are insufficient to fully address the problems associated with shale gas development, this recommendation provides the Commonwealth with a way to provide a socially beneficial outcome that should, for all intents and purposes, pay for itself.

Furthermore, the gas fund must avoid the problems that other states and nation-states have encountered. It makes sense operationally to establish this fund constitutionally, like Alaska has, while at the same time removing all funding streams and persistent accumulated funds from the omnibus budget of the Commonwealth. This will eliminate the possibility of future lawmakers succumbing to political and financial expediency by mortgaging the future needs the gas fund is intended to address. Since this fund is designed specifically to address problems associated with shale gas development, it must be stressed that decisions for all expenditures from the fund must be outside the purview of the legislative body once the fund has been established.

5.2.2.2 Recommendation #2

The source of financing for the fund mentioned above should be tied directly to shale gas extraction, and should be a combination of per-well fees as well as a comprehensive severance tax on total volumes of natural gas extracted. By applying up-front charges per well for infrastructure degradation and water usage based upon the models in Chapter 4, the fund will have sufficient capital to both address problems proactively and to address and react to problems as they develop.

As mentioned above, the gas fund must be sufficiently funded in order to provide appropriate mitigative assistance where needed. Therefore, the source of financing for the fund must be tied directly to shale gas extraction. The only way to do this fairly is to create a funding structure based on a combination of per-well fees and a comprehensive severance tax on total volumes of natural gas extracted. By applying up-front charges similar in practice to user fees per well for infrastructure degradation, and water usage based upon the models provided in Chapter 4, the fund should have sufficient capital to both address problems proactively and to address and react to problems as they develop.

Since the issue of a severance tax has been shelved indefinitely by Governor Tom Corbett, it remains questionable whether such a scheme could be successfully implemented in the near future, particularly in light of the effectiveness of the industry lobby. Pennsylvania remains the only state in the country with a substantial, currently active natural gas extraction operation and without some form of severance tax. Once Pennsylvanians begin to observe the scale of associated negative externalities caused by shale gas development, it stands to reason that Pennsylvanians will agitate for the application of such a tax. While this approach in precludes the ability to proactively address many problems, the likelihood of a tax being applied most certainly increases.

5.2.2.3 Recommendation #3

The Commonwealth should require that all water usage for shale gas development must be paid for according to fair market value, via volume fees for all water usage. Policymakers should also recognize that innovation can be fueled and fostered by way of proactive policies that enforce new market realities upon specific actors. By charging drilling companies for all water used in the fracking process, the Commonwealth will essentially create a financial incentive for operators to develop new and less water-intensive processes, including, but not limited to, better recycling technology or water-free fracking technology.

Operators should pay fair market value to the state for the privilege of using Pennsylvania water supplies. By taking this approach, the Commonwealth will be directly fostering innovation in the realm of water treatment, as well as providing more funding for potential remediation efforts associated with shale gas extraction. By charging drilling companies for all water used in the shale gas drilling process, the Commonwealth will establish a financial incentive for operators to develop new and less water-intensive processes, including, but not limited to, better recycling technology and water-free fracking technology.

5.2.3 Rationale and Implementation

Such policy alterations are based on the experiences observed during the development of the Barnett formation, as well as preliminary indications from initial activity in the Marcellus formation. As companies develop more wells with current technology, ever-greater volumes of water will be needed, and further road degradation will occur, exacerbated both by well development in primarily rural areas and the temperate climate of the region. Moreover, it should be noted that these issues should not be presumed to represent all potential, or even likely, negative associative effects stemming from shale gas development. Therefore, policies and funding options must be of sufficient size to allow for addressing such unforeseen or expected negative externalities.

The question remains, how can a gas fund contribute specifically to some of these negative impacts in ways that a severance tax or usage fee won't? There are a number of different types of natural resource funds, each with their own purpose and function. Alaska's fund, for example, is controlled by the state legislature, and functions much like a pension, whereby every Alaskan receives a yearly disbursement. Contrast that with the Azerbaijani fund, designed essentially as an earmark for the benefit of future generations. And of course, there are other funds – stability funds – like in Norway, wherein the purpose is to provide sufficient revenue for a central budget in case the overall value of hydrocarbons changes dramatically, thereby negatively affecting royalties, upon which the national budget relies.

In Pennsylvania, as mentioned above, there exists no severance tax and hence, no statewide budgetary reliance on royalty income. Furthermore, while there is a tradition of viewing the mineral wealth beneath the feet of Pennsylvanians as a nominally communal resource for benefit of the commonweal, the truth is that the way in which modern capitalism manifests itself in the United States downplays such communitarian notions of collective wealth, and thus there remains little motivation to impose such paradigm upon the natural gas industry.

In addition, Pennsylvania benefits from being a component of a much larger, much more deeply and widely diversified economy whereby many of the more troubling economic concerns associated with extractive industries – namely the Dutch disease and resource curse, characterized by a generalized inflation – would seem to be less of a problem.

Yet, many undeniable complications do present themselves. As made clear by the research presented earlier in this work, those problems will manifest in areas least likely to possess the capability to address them in any meaningful, effective way. Thus, Pennsylvania will be forced to set a new precedent, whereby the state borrows liberally from the funds that work, and dispose of the aspects of these funds that would not only be inappropriate for Pennsylvania policy issues, but could potentially lead to larger problems down the road.

Hence, the establishment of the gas fund in Pennsylvania should focus on the mechanics of how the fund is to operate - specifically, how the fund is managed, how the disbursement of money from the fund will be carried out, and how its ability to satisfy particular social problems can be distinguished from a tax or fee.

While insulating the domestic economy in Pennsylvania from the flow of hard currency does not present itself as a necessarily notable problem, the multitude of other attendant problems which would necessitate the creation of such a fund provides ample justification for establishing a fund that works, on the local level, as a stabilization fund.

Paradoxically, the Pennsylvania Gas Fund should have at once a very broad and yet a very narrow mandate. On the one hand, the fund should have the latitude to address problems that have not yet been identified but that may manifest themselves as development of the shale reserves proceeds. On the other, the fund must be sufficiently constrained, by state legislative mandate, so that the function of the fund focuses only on localities negatively affected by the shale development, either directly or indirectly.

Ideally, the fund would require a separate bureaucracy that would focus primarily on tracking development of the shale gas reserves and the attendant effects that manifest as that development increases. The aim of such a separate bureaucracy would be to insulate the fund from arbitrary political power struggles and cronyism – problems that would fundamentally undermine the entire purpose of the fund. The best way to successfully endeavor to do something along these lines would be to elicit the help of various institutions of higher learning in the Commonwealth, the interest of which is public service and the pursuit of knowledge for the benefit of society at large. Not only would leveraging universities reduce overhead, the fund would be able to synergistically partner with universities in such a way that the state can develop its own class of specialists.

Hence, with adequate funding, proper oversight, a premium placed upon both independent research and the public good – both for the function of the fund itself and for policy consistency moving into the future, the Pennsylvania Natural Gas Fund would prove to be an effective and efficient arbiter of the potential problems and solutions related to shale gas development throughout the state.

Chapter 6: Future Work

Following the investigations described in this thesis, a number of projects could begin, involving both the models established in Chapter 4 as well as the creation of new models. While this work should not be presumed to be comprehensive, this work opens the door for future research in the realm of other externalities. This research addresses only two discrete components of budgetary and microeconomic effects of shale gas development, and explores a well-established effective solution for those problems.

One of the main attendant effects of shale gas development that was not addressed is housing prices, particularly localized prices in 'hot' areas. One of the problems lies with insufficient data sources to explore the problems. However, with proper funding and a sufficient time horizon, many of these difficulties could be remedied.

Another effect of concern is sectoral inflation, particularly as it relates to the labor market. As noted in Chapter 2, one of the major problems in other nations particularly is the deindustrialization of certain regions as a direct result of extractive industries. While this problem has been explored in other nations to some degree, it remains to be seen whether any research has been pursued in the United States directly relating to extractive industries. This goes beyond mere boom/bust cycles. Rather, the economic incentives on the part of laborers tends to drive this particular trend.

While this is a small portion of the potential research opportunities that shale gas development provides, this short list provides substantial research options moving forward.

BIBLIOGRAPHY

Abdalla, Charles, and Joy Drohan. "Water Withdrawals for Development of Marcellus Shale Gas in Pennsylvania." College of Agricultural Sciences Publications. N.p., n.d. Web. 8 Nov. 2010. <http://pubs.cas.psu.edu/PubTitle.asp?varTitle=marcellus&Submit=Go>.

"Addendum to the 1997 Federal Highway Cost Allocation Study Final Report." Home | Federal Highway Administration. US Dept. of Transportation - Federal Highway Administration, n.d. Web. 20 Mar. 2013. <http://www.fhwa.dot.gov/policy/hcas/addendum.htm>.

"Advocates for Highway and Auto Safety." www.saferoads.org. Advocates for Highway and Auto Safety, n.d. Web. 20 Feb. 2011. <www.saferoads.org/issues/fs-trucks.htm>.

All, Consulting. "U.S. Unconventional Gas Outlook." U.S. Unconventional Gas Outlook 1 (2008): All. Print.

Allen, Robert (1979). “International Competition in Iron and Steel, 1850-1913,” Journal of Economic History 39: 911-37.

Anderson, M. P., Woessner, W. W., 1992, Applied Groundwater Modeling; Simulation of Flow and Advective Transport: Academic Press, Inc. pg. 1-381.

Andersen, Sveien S. (1993). The Struggle over North Sea Oil and Gas: Government Strategies in Denmark, Britain, and Norway. Oslo: Scandinavian University Press.

Ascher, William (1999). Why Governments Waste Natural Resources. Baltimore: Johns Hopkins University Press.

Auty, Richard M., ed. (2001). Resource Abundance and Economic Development. Prepared for the World Institute for Development Economics Research of the United Nations University (UNU/WIDER). Oxford: Oxford University Press.

Auty, Richard M. (1998). Resource Abundance and Economic Development. Helsinki: UNU World Institute for Development Economics Research.

Baker, Rose M. and Passmore, David Lynn, Benchmarks for Assessing the Potential Impact of a Natural Gas Severance Tax on the Pennsylvania Economy (September 13, 2010). Available at SSRN: http://ssrn.com/abstract=1667022.

"Barnett Shale Impact Study."http://www.barnettshaleexpo.com. The Perryman Group, n.d. Web. 10 Feb. 2011<www.barnettshaleexpo.com/docs/Barnett_Shale_Impact_Study.pdf>.

"Barnett Shale Production: Water Management."http://www.askchesapeake.com. Chesapeake Energy, n.d. Web. 15 Jan. 2011. <www.askchesapeake.com/Barnett-Shale/Production/Pages/WaterManagement.aspx>.

"Barnett Water Use Fact Sheet."http://www.chk.com. Chesapeake Energy, n.d. Web. 11 Feb. 2011. <www.chk.com/Media/BarnettMediaKits/Barnett_Water_Use_Fact_Sheet.pdf>.

Bené, James E., and Robert Harden. "Northern Trinity / Woodbine Aquifer Groundwater Availability Model." The Texas Water Development Board. R.W. Harden & Associates, Inc., 31 Aug. 2004. Web. 9 Mar. 2013. <www.twdb.state.tx.us/groundwater/models/gam/trnt_n/TRNT_N_Model_Report.pdf>.

Bené, James E., and Robert Harden. "Northern Trinity/Woodbine GAM Assessment of Groundwater Use in the Northern Trinity Aquifer Due To Urban Growth and Barnett Shale Development." Texas Water Development Board. R. W. Harden & Associates, Inc., 11 Jan. 2007. Web. 9 Mar. 2013. <http://www.twdb.state.tx.us/groundwater/models/gam/trnt_n/TRNT_N_Barnett_Shale_Report.pdf>.

Bennett, Andra. "Barnett Shale Still a Major Stimulus to Texas." Barnett Shale Expo. N.p., 11 Mar. 2009. Web. 8 Nov. 2010. <http://www.barnettshaleexpo.com>.

Bennett, Andra. "Texas Energy Sector Booming." Barnett Shale Expo. The Perryman Group, 28 Mar. 2008. Web. 8 Nov. 2010. <http://www.barnettshaleexpo.com>.

Blainey, Geoffrey (1993). The Rush That Never Ended: A History of Australian Mining. Melbourne: Melbourne University Press. Fourth Edition.

Bohn, Henning, and Robert T. Deacon (2000). “Ownership Risk, Investment, and the Use of Natural Resources,” American Economic Review 90: 526-549.

Bredehoeft, J.D., S.S., Papadopulos and Cooper, H.H. 1982. Groundwater: The Water Budget Myth. Scientific Basis of Water Management: National Academy of Sciences Studies in Geophysics, pg. 51-57.

"Brent Crude - Wikipedia, the free encyclopedia." Wikipedia, the free encyclopedia. N.p., n.d. Web. 10 Mar. 2013. <http://en.wikipedia.org/wiki/Brent_Crude>.

Byrd, C.L., 2007, Updated evaluation for the Central Texas Trinity Aquifer Priority Groundwater Management Area, Priority Groundwater Management Area File Report: Austin, TX, Texas Commission on Environmental Quality, Water Rights Permitting and Availability Section, Water Supply Division, pp. 160.

Campbell, C. J., and R. C. Duncan. The coming oil crisis. Brentwood, Essex, England: Multi-Science Pub. Co. & Petroconsultants, 1997. Print.

"CFR-2008-title23-vol1-sec658-17.pdf."FHA: DOT. Federal Highway Administration, DOT , n.d. Web. 10 Mar. 2013. <edocket.access.gpo.gov/cfr_2008/aprqtr/pdf/23cfr658.17.pdf>.

"Chemicals Used In Hydraulic Fracturing." United States House of Representatives Committee of Energy and Commerce - Minority Staff. U.S. House of Representatives, n.d. Web. 9 Mar. 2013. <http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic-Fracturing-Chemicals-2011-4-18.pdf>.

"Chesapeake Energy's Permit to Use State Route 1007 in Bradford County Revoked Until Damage is Repaired | Marcellus Drilling News." Marcellus Drilling News. N.p., n.d. Web. 10 Mar. 2013. <http://marcellusdrilling.com/2010/04/chesapeake-energys-permit-to-use-state-route-1007-in-bradford-county-revoked-until-damage-is-repaired/>.

"China to speed up shale gas development." China Daily Website - Connecting China Connecting the World. N.p., n.d. Web. 10 Mar. 2013. <http://www.chinadaily.com.cn/china/2011-03/24/content_12224287.htm>.

"CIA Factbook - Norway." https://www.cia.gov/library/publications/the-world-factbook/geos/no.html. Central Intelligence Agency, n.d. Web. 9 Mar. 2013. <https://www.cia.gov/library/publications/the-world-factbook/geos/no.html>.

"CIA World Factbook - Venezuela."www.cia.gov. Central Intelligence Agency, n.d. Web. 9 Mar. 2013. <https://www.cia.gov/library/publications/the-world-factbook/geos/ve.html>.

Claes, Dag Harald. The politics of oil-producer cooperation. Boulder, Colo.: Westview Press, 2001. Print.

"Combination truck definition by Babylon's free dictionary." Free Online Dictionary. Babylon, Ltd., n.d. Web. 9 Mar. 2013. <http://dictionary.babylon.com/combination_truck/>.

Considine, Timothy, Robert Watson, Rebecca Entler, and Jeffrey Sparks. "An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play." An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play. The Pennsylvania State University College of Earth & Mineral Sciences Department of Energy and Mineral Engineering, 5 Aug. 2009. Web. 8 Nov. 2010. <www.alleghenyconference.org/.../PSUStudyMarcellusShale072409.pdf>.

Considine, Timothy J., Robert Watson, and Seth Blumsack. The Economic Impacts of the Pennsylvania Marcellus Shale Natural Gas Play: An Update. State College: !e Pennsylvania State University College of Earth and Mineral Sciences Department of Energy and Mineral Engineering, 2010. Print.

Cotet, Anca Maria and Tsui, Kevin K., Oil and Conflict: What Does the Cross-Country Evidence Really Show? (February 8, 2010). Available at SSRN: http://ssrn.com/abstract=1347700 or http://dx.doi.org/10.2139/ssrn.1347700

Culver, W.W., and C.J. Reinhart (1989). "Capitalist Dreams: Chile's Response to Nineteenth Century World Copper Competition," Comparative Studies in Society and History 31.

David, Paul A., and Gavin Wright (1997). "Increasing Returns and the Genesis of American Resource Abundance," Industrial and Corporate Change 6

Deacon, R.E., H.E. Frech, and M.B. Johnson (1990) Taxing Energy: Oil Severance Taxation and the Economy, The Independent Institute, 176 pages.

Deffeyes, Kenneth S.. Hubbert's peak: the impending world oil shortage. Princeton, N.J.: Princeton University Press, 2001. Print.

Delaware Riverkeeper." Delaware Riverkeeper. N.p., n.d. Web. 10 Mar. 2013. <http://www.delawareriverkeeper.org/>.

"Democrats - Energy/Commerce - House."democrats.energycommerce.house.gov. Democratic Party , n.d. Web. 10 Feb. 2011. <democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf>.

"DISCOS." Texas Department of Transportation. TxDOT, n.d. Web. 9 Mar. 2013. <http://www.txdot.gov/inside-txdot/division/finance/discos.html>.

"Earthquakes." Arkansas Geological Survey. N.p., n.d. Web. 10 Mar. 2013. <http://www.geology.ar.gov/geohazards/earthquakes.htm>.

"EIA - Natural Gas Pipeline Network - Transporting Natural Gas in the United States." Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government. N.p., n.d. Web. 10 Mar. 2010. <http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline>.

Engelder, T. (2009) "Marcellus 2008: Report card on the breakout year for gas production in the Appalachian Basin," Fort Worth Basin Oil and Gas Magazine, 2009.

Engelder, Terry, and Gary G. Lash. "Marcellus Shale Play's Vast Resource Potential Creating Stir in Appalachia." The American Oil & Gas Reporter. The American Oil & Gas Reporter, n.d. Web. 10 Nov. 2010. <www.geosc.psu.edu/~jte2/references/link150.pdf>.

Eriksen, Tony. "The Oil Drum | World Oil Production Peaked in 2008." The Oil Drum | Discussions about Energy and Our Future. N.p., 17 Mar. 2009. Web. 12 Nov. 2010. <http://www.theoildrum.com/node/5177>.

"EXCESSIVE TRUCK WEIGHT: AN EXPENSIVE BURDEN WE CAN NO LONGER SUPPORT." www.gao.gov. Government Accounting Office, n.d. Web. 11 Mar. 2013. <archive.gao.gov/f0302/109884.pdf>.

"ExplorePAHistory.com - Stories from PA History." ExplorePAHistory.com. N.p., n.d. Web. 10 Mar. 2013. <http://explorepahistory.com/storydetails.php?storyId=1-9-C&chapter=1>.

Ferranti, David de; Guillermo E. Perry; Daniel Lederman; and William F. Maloney (2002). From Natural Resources to the Knowledge Economy. The World Bank: Washington, D.C.

"Flowback water - Wikimarcellus."Wikimarcellus. N.p., n.d. Web. 8 Dec. 2010. <http://www.waytogoto.com/wiki/index.php/Flowback_water>.

Fortson, Danny . "Shale gas blasts open world energy market." The Sunday Times [London] 1 Nov. 2009, 1 ed., sec. Business: 11. The Sunday Times. Web. 8 Mar. 2010.

"Fracking the Life Out of Arkansas and Beyond." www.inteldaily.com. N.p., n.d. Web. 10 Feb. 2011. <http://inteldaily.com/2011/01/fracking-the-life-out-of-arkansas-and-beyond/>.

Frantz, J.K., and V. Jochen. "Shale Gas White Paper." Schlumberger Marketing Communications 05-OF299 (2005): All. Print.

Fwa, T. F.. The handbook of highway engineering . Boca Raton: Taylor & Francis, 2006. Print.

Gabbard, Keith . Phone interview. 30 Mar. 2011.

"Gas Business Briefing." Gas Business Briefing. N.p., 14 Apr. 2011. Web. 10 Mar. 2013. <http://www.gasbb.com/>.

Gelsi, Steve. "Exxon CEO weighs effects of $4 gasoline - MarketWatch."MarketWatch - Stock Market Quotes, Business News, Financial News. N.p., n.d. Web. 10 Mar.

2013. <http://www.marketwatch.com/story/exxon-ceo-weighs-effects-of-4-gasoline-2011-03-09>.

Gilardoni, Andrea. The world market for natural gas implications for Europe. Berlin: Springer, 2008. Print.

"Government Pension Fund Global."Norges Bank Investment Management. Norges Bank, n.d. Web. 7 Dec. 2010. <www.nbim.no/en/About-us/Government-Pension-Fund-Global/>.

Government Pension Fund Global - NBIM. (n.d.). NBIM - NBIM. Retrieved March 10, 2013, from http://www.nbim.no/en/About-us/Government-Pension-Fund-Global/
Kennedale, Texas. (n.d.).

Green, Elwin. "Birth of an industry - Pittsburgh Post-Gazette." Pittsburgh Post-Gazette. N.p., n.d. Web. 10 Mar. 2013. <http://www.post-gazette.com/pg/09239/993526-28.stm>.

Hanneson, Rognvaldur (2001). Investing for Sustainbability: The Management of Mineral Wealth Boston: Kluwer Academic.

Harper, John A. . "The Marcellus Shale—An Old “New” Gas Reservoir in Pennsylvania." Pennsylvania Geology. Version Vol. 38, No. 1. Bureau of Topographic and Geologic Survey, n.d. Web. 9 Mar. 2013. <www.dcnr.state.pa.us/cs/groups/public/documents/document/dcnr_006811.pdf>.

Harris, DeVerle P. (1993). “Mineral Resource Stocks and Information,” in Allen V. Kneese and James L. Sweeney (eds.), Handbook of Natural Resource and Energy Economics, Volume III. North-Holland.

Hartgen, David T. , Ravi K. Karanam, M. Gregory Fields , Travis A. Kerscher, and Adrian T. Moore. "19th Annual Report on the Performance of State Highway Systems (1984-2008)."http://reason.org/. Reason, n.d. Web. 10 Mar. 2013. <reason.org/files/19th_annual_highway_report.pdf>.

Harvey, C., and J. Press (1990). International Competition and Industrial Change: Essays in the History of Mining and Metallurgy, 1800-1950. London.

Hausman, Ricardo (2003). “Venezuela’s Growth Implosion: A Neoclassical Story?” in Dani Rodrik (ed.), In Search of Prosperity. Princeton: Princeton University Press.

Heimel, Steve . "Less Oil in Petroleum Reserve-Alaska than Estimated | Alaska Public Media." alaskapublic.org. N.p., n.d. Web. 20 Mar. 2013. <http://www.alaskapublic.org/2011/05/06/less-oil-in-petroleum-reserve-alaska-than-estimated-2/>.

"Highway Cost Allocation Study - Office of Transportation Policy Studies - FHWA."Home | Federal Highway Administration. N.p., n.d. Web. 10 Mar. 2013. <http://www.fhwa.dot.gov/policy/otps/costallocation.htm>.

Hopey, Don. "Golden algae to blame for Dunkard Creek fish kill." Post-Gazette.com. N.p., n.d. Web. 8 Dec. 2010. <http://www.post-gazette.com/pg/09268/1000694-113.stm>.

Hotelling, Harold (1931). "The Economics of Exhaustible Resources," Journal of Political Economy 39: 137-175.

Hubbert, M. King. "Nuclear Energy and the Fossil Fuels." The Coming Global Oil Crisis. N.p., n.d. Web. 1 Apr. 2010. <www.hubbertpeak.com/hubbert/1956/1956.pdf>.

"Hydraulic fracturing - Wikipedia, the free encyclopedia." Wikipedia, the free encyclopedia. N.p., n.d. Web. 10 Mar. 2010. <http://en.wikipedia.org/wiki/Hydraulic_fracturing>.

"Institute for Transportation at Iowa State University." Institute for Transportation at Iowa State University. N.p., n.d. Web. 10 Mar. 2013. <http://www.intrans.iastate.edu/pubs/midcon2009/LiuDamage.pdf>.

"Kennedale, Texas." Chesapeake Energy - Natural Gas Operations - Shale Community News & Information. N.p., n.d. Web. 10 Mar. 2013. <http://www.askchesapeake.com/Barnett-Shale/Neighborhood/Kennedale/Pages/information.aspx>.

Keppler, Hans , Christopher F. Pearson, Robert M. Potter, and James N. Albright. "Geothermal Resources Council 1983 Annual Meeting." MICROEARTHQUAKES INDUCED DURING HYDRAULIC FRACTURING AT THE FENTON HILL HDR SITE: THE 1982 EXPERIMENTS. Los Alamos National Laboratory: University of California for the United States Dapartment of Energy, 27 Oct. 1983. Web. 9 Mar. 2013. <www.osti.gov/geothermal/servlets/purl/5703581-lT69dU/native/5703581.pdf>.

Krautkraemer, Jeffrey A. (1998). "Nonrenewable Resource Scarcity," Journal of Economic Literature 36 (December 1998): 2065-2107.

Leamer, Edward (1984). Sources of Comparative Advantage. Cambridge MA: MIT Press.

Levisohn , Ben . "The Alaska Permanent Fund Loses $10 billion - BusinessWeek."Businessweek - Business News, Stock market & Financial Advice. N.p., n.d. Web. 10 Mar. 2013. <http://www.businessweek.com/investing/insights/blog/archives/2008/11/the_alaska_permanent_fund_loses_10_billion.html>.

Luskin, David M. , and C. Michael Walton. "Effects of Truck Size and Weights on Highway Infrastructure and Operations."http://www.utexas.edu/. University of Texas, n.d. Web. 10 Mar. 2013. <www.utexas.edu/research/ctr/pdf_reports/2122_S.pdf>.

Lustgarten, Abrahm. "State Oil and Gas Regulators Are Spread Too Thin to Do Their Jobs - ProPublica."ProPublica. N.p., 30 Dec. 2009. Web. 8 Nov. 2010. <http://www.propublica.org/article/state-oil-and-gas-regulators-are-spread-too-thin-to-do-their-jobs-1230>.

Maloney, William F. (2002). "Missed Opportunities: Innovation and Resource-Based Growth in Latin America," Economia 3: 111-150.

Mantell, Matthew E. . "Deep Shale Natural Gas: Abundant, Affordable, and Surprisingly Water Efficient."http://www.energyindepth.org/. Chesapeake Energy Corporation, 16 Sept. 2009. Web. 9 Mar. 2013. <www.energyindepth.org/wp-content/uploads/2009/03/MMantell_GWPC_Water_Energy_Paper_Final.pdf>.

Manzano, Osmel, and Roberto Rigobon (2001). "Resource Curse or Debt Overhang?" NBER Working Paper 8390 (July).

"Marcellus Gas Well Hydrofracture Wastewater Disposal by Recycle Treatment Process." ProChemTech International, Inc.. N.p., n.d. Web. 8 Nov. 2010. <http://prochemtech.com>.

"Marcellus Shale." Pennsylvania Dept. of Environmental Protection. Pennsylvania DEP: Bureau of Oil and Gas Management, n.d. Web. 9 Mar. 2013. <www.portal.state.pa.us/portal/server.pt/community/marcellus_shale/20296>.

"Marcellus Shale Coalition —." Marcellus Shale Coalition —. N.p., n.d. Web. 10 Mar. 2013. <http://marcelluscoalition.org/>.

"Marcellus Shale Coalition - SourceWatch." SourceWatch. N.p., n.d. Web. 10 Mar. 2013. <http://www.sourcewatch.org/index.php?title=Marcellus_Shale_Coalition>.

"Marcellus Shale Production."www.fractracker.org. FracTracker Alliance, n.d. Web. 15 Mar. 2011. <www.fractracker.org/2010/09/marcellus-shale-production-data-good.html>.

"Marcellus Shale gas drilling - Photos of Marcellus Shale gas wells in Pennsylvania at marcellus-shale.us." Marcellus Shale gas drilling - Photos of Marcellus Shale gas wells in Pennsylvania at marcellus-shale.us. N.p., n.d. Web. 10 Mar. 2013. <http://www.marcellus-shale.us/>.

"Marcellus Shale: Well Cost." Haynesville Shale. N.p., n.d. Web. 10 Mar. 2013. <http://shale.typepad.com/marcellusshale/well-cost/>.

"Marcellus Water Use Fact Sheet."www.chk.com. Chesapeake Energy, n.d. Web. 2 Feb. 2011. <www.chk.com/Media/MarcellusMediaKits/Marcellus_Water_Use_Fact_Sheet.pdf>.

"Maricopa County." Maricopa County, Arizona. N.p., n.d. Web. 10 Mar. 2010. <http://www.maricopa.gov/EnvSvc/AboutUs/Enforcement/IllDump.aspx>.

McFarland, Greg . "Shale Economics: Watch the Curve : Oil and Gas Evaluation Report." Oil and Gas Evaluation Report : Oil & Gas Evaluation Professionals : Obsidian Energy Company : Â· Seismic Interpretation, Petroleum Engineering. N.p., n.d. Web. 10 Mar. 2013. <http://www.oilandgasevaluationreport.com/2010/03/articles/oil-patch-economics/shale-economics-watch-the-curve/>.

McFerron, Whitney , and Elizabeth Campbell . "Worst Texas Drought in 44 Years Damaging Wheat Crop, Reducing Cattle Herds - Bloomberg." Bloomberg - Business, Financial & Economic News, Stock Quotes. N.p., n.d. Web. 10 Mar. 2013. <http://www.bloomberg.com/news/2011-03-24/worst-texas-drought-in-44-years-eroding-wheat-beef-supply-as-food-rallies.html>.

Mills, Robin M.. The myth of the oil crisis: overcoming the challenges of depletion, geopolitics, and global warming. Westport, Conn.: Praeger, 2008. Print.

Moors, Kent F. The Vega Factor Oil: Volatility and the Next Global Crisis. Hoboken, New Jersey: John Wiley & Sons, Inc., 2011. Print.

"Natural Gas 1998: Issues and Trends." www.eia.doe.gov. Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government., n.d. Web. 10 Mar. 2010. <www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/natural_gas_1998_issues_trends/pdf/it98.pdf>.

"NaturalGas.org." NaturalGas.org. N.p., n.d. Web. 10 Mar. 2010. <http://www.naturalgas.org/overview/background.asp>.

"Natural Gas Play Definition." Oil Gas Glossary. N.p., n.d. Web. 7 Dec. 2010. <oilgasglossary.com/definition/natural-gas-play-definition.html>.

Nickerson, Joel . Phone interview. 10 Mar. 2011.

Nicot, Jean-Philippe, and Eric Potter. "Northern Trinity/Woodbine GAM Assessment of Groundwater Use in the Northern Trinity Aquifer Due To Urban Growth and

Barnett Shale Development."http://www.twdb.state.tx.us/. Texas Water Development Board, n.d. Web. 10 Mar. 2013. <http://www.twdb.state.tx.us/groundwater/models/gam/trnt_n/TRNT_N_Barnett_Shale_Report.pdf>.

Noreng, Øystein (2002). “Maintaining North Sea Output by Restructuring the Norwegian Petroleum Industry,” The Journal of Energy and Development 27: 213-236.

"North Sea Brent Crude Definition | Investopedia." Investopedia - Educating the world about finance. N.p., n.d. Web. 10 Mar. 2013. <http://www.investopedia.com/terms/n/northseabrentcrude.asp>.

"Norway - Wikipedia, the free encyclopedia." Wikipedia, the free encyclopedia. N.p., n.d. Web. 10 Mar. 2013. <http://en.wikipedia.org/wiki/Norway>.

Nuttall, Brandon C. . "Predicting Cumulative Production of Devonian Shale Gas Wells from Early Well Performance Data, Appalachian Basin of Eastern Kentucky." http://www.uky.edu/. U. S. Geological Survey, 17 Nov. 2007. Web. 10 Mar. 2013. <www.uky.edu/KGS/emsweb/devsh/production/esaapg07_Nuttall.pdf>.

"PermitDrilledmaps." DEP Homepage. N.p., n.d. Web. 10 Mar. 2013. <http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2010PermitDrilledmaps.htm>.

"Pittsburgh Water and Sewer Authority - Water Rates." Pittsburgh Water and Sewer Authority - Home. N.p., n.d. Web. 10 Mar. 2013. <http://www.pgh2o.com/fees.htm>.

Prince, Jeff. "FWWeekly: Feature: Til Your Wells Run Dry." FWWeekly: Wednesday, April 15, 2009. N.p., n.d. Web. 10 Mar. 2010. <http://archive.fwweekly.com/content.asp?article=1004>.

"Quarterly Summary of State and Local Government Tax Revenue." U.S. Census Bureau. U.S. Census Bureau, 27 Sept. 2010. Web. 11 Nov. 2010. <>.

"Recreation For All."www.delawareriverkeeper.org. Delaware Riverkeeper Network, n.d. Web. 9 Mar. 2013. <delawareriverkeeper.org/pdf/Recreation_for_All.pdf>.

"Regional Summary - White Paper. Proposed Gas Drilling in the Upper Delaware River Basin Watershed."DamascusCitizens.org. Damascus Citizens for Sustainability, n.d. Web. 10 Nov. 2010. <www.damascuscitizens.org/Gas-Drilling_WhitePaper.pdf>.

Richter, Stephan-Götz . "The Immigration Safety Valve: Keeping a Lid on Inflation | Foreign Affairs." Home | Foreign Affairs. N.p., n.d. Web. 10 Mar. 2013.

<http://www.foreignaffairs.com/articles/55841/stephan-g%C3%83%C2%B6tz-richter/the-immigration-safety-valve-keeping-a-lid-on-inflation>.

Ridgeway, C., 2006, Barnett Shale study area water well analysis using Texas Department of Licensing and Regulation driller's report records: Groundwater Resources Division, Texas Water Development Board, Analysis Paper 06-28.

"RIGZONE - Devon Taps Ecosphere for Recycle-Produced Water at Barnett Shale." RIGZONE - Your Gateway to the Oil & Gas Industry. N.p., n.d. Web. 10 Mar. 2013. <http://www.rigzone.com/news/article.asp?a_id=62370>.

"Road Bonding." Keystone Energy Forum. N.p., n.d. Web. 13 Mar. 2013. <www.keystoneenergyforum.com/uploads/files/18/RoadBonding.pdf>.

"Road damage from heavy truck traffic to gas drilling sites on Marcellus Shale."Marcellus Shale gas drilling - Photos of Marcellus Shale gas wells in Pennsylvania at marcellus-shale.us. N.p., n.d. Web. 10 Mar. 2013. <http://www.marcellus-shale.us/road_damage.htm>.

Robertson, Campbell. "A Dot on the Map, Until the Earth Started Shaking - NYTimes.com." The New York Times - Breaking News, World News & Multimedia. N.p., n.d. Web. 10 Mar. 2013. <http://www.nytimes.com/2011/02/06/us/06earthquake.html>.

Sachs, Jeffrey D., and Andrew M. Warner (1997). "Natural Resources and Economic Growth," revised. Harvard Institute for International Development, Discussion Paper.

Sachs, Jeffrey D., and Andrew M. Warner (2001). "The Curse of Natural Resources," European Economic Review 45: 827-838.

Sachs, Jeffrey D. (2001). "Tropical Underdevelopment," NBER Working Paper 8119 (Feb).

Sala-I-Martin, Xavier, and Arvind Subramanian (2003) "Addressing the Natural Resource Curse: An Illustration from Nigeria," NBER Working Paper 9804 (June).

"Severance Tax." enacademic.com. Academic, n.d. Web. 9 Mar. 2013. <investment_terms.enacademic.com/12812/Severance_Tax>.

Shankman, Sabrina. "Gas Drillers Plead Guilty to Felony Dumping Violations - ProPublica." ProPublica - Journalism in the Public Interest. N.p., n.d. Web. 10 Mar. 2010. <http://www.propublica.org/feature/gas-drillers-plead-guilty-to-felony-dumping-violations>.

"Shale Gas Reservoirs-Transform Software and Services, Inc.." Transform Software and Services-Transform Software and Services, Inc.. N.p., n.d. Web. 10 Mar. 2013. <http://www.transformsw.com/papers-and-presentations/studies.html>.

"Shared Costs, Shared Resources State Distribution of Severance Tax Revenues."http://www.marcellus-shale.us/. Pennsylvania Budget and Policy Center, 15 June 2009. Web. 9 Mar. 2013. <www.marcellus-shale.us/pdf/Gas-Severance-Tax-Dist.pdf>.

Soeder, Daniel J., William Kappel, 2007, Updated evaluation for the Central Texas Trinity Aquifer Priority Groundwater Management Area, Priority Groundwater Management Area File Report: Austin, TX, Water Rights Permitting, Availability Section, Water Supply Division, and 160 p.. "Marcellus Shale Water Resources and Natural Gas Production." Geology.com: News and Information for Geology & Earth Science. N.p., n.d. Web. 10 Mar. 2013. <http://geology.com/usgs/marcellus-shale/>.

Soeder, Daniel J., and William M. Kappel. "Water Resources and Natural Gas Production from the Marcellus Shale." USGS Publications Warehouse. Version Fact Sheet 2009-3032. N.p., n.d. Web. 12 Nov. 2010. <http://pubs.usgs.gov/fs/2009/3032/>.

Spitz, Peter H. (1988). Petrochemicals: The Rise of an Industry. New York: John Wiley & Sons.

Stringer, Jerry . Phone interview. 12 Feb. 2011.

Surowiecki, James (2001). “The Real Price of Oil,” The New Yorker, December 3, 2001.

"Swamp Angel Energy Guilty of Illegally Dumping 200K Gallons of Brine in PA | Marcellus Drilling News." Marcellus Drilling News. N.p., n.d. Web. 10 Mar. 2010. <http://marcellusdrilling.com/2010/02/swamp-angel-energy-guilty-of-illegally-dumping-200k-gallons-of-brine-in-pa/>.

"The AASHO Road Test Report 5: Pavement Research." The Highway Research Board. The Highway Research Board Of The NAS-NRC Division Of Engineering And Industrial Research, n.d. Web. 31 Jan. 2011. <www.saferoads.org/issues/fs-trucks.htm>.

Tilton, John E. (2003). On Borrowed Time? Assessing the Threat of Mineral Depletion. Washington, D.C.: Resources for the Future.

Tsalik, Svetlana, and Robert E. Ebel. Caspian oil windfalls: who will benefit?. Philadelphia, Pa.: Open Society Institute, Central Eurasia Project, 2003. Print.

Urbina, Ian. "Regulation Lax as Gas Wells' Tainted Water Hits Rivers."http://www.nytimes.com/. New York Times, 26 Feb. 2011. Web. 10 Mar. 2011. <www.nytimes.com/2011/02/27/us/27gas.html >.

"U.S.-China Clean Energy Announcements | The White House." The White House. N.p., n.d. Web. 10 Mar. 2013. <http://www.whitehouse.gov/the-press-office/us-china-clean-energy-announcements>.

"US Drought Monitor." US Drought Monitor. N.p., n.d. Web. 10 Mar. 2013. <http://droughtmonitor.unl.edu/>.

U.S. Geological Survey, MD-DE-DC Water Science Center, 5522 Research Park Drive, Baltimore, MD 21228.

U.S. Geological Survey, New York Water Science Center, 30 Brown Road, Ithaca, NY 14850.

"U.S. Shale Gas: An Unconventional Resource. Unconventional Challenges."www.halliburton.com. N.p., n.d. Web. 10 Mar. 2013. <www.halliburton.com/public/solutions/contents/shale/related_docs/H063771.pdf >.

Vanderklippe, Nathan. "Encana's backing bolsters case for natural gas export terminal - The Globe and Mail." Home - The Globe and Mail. N.p., n.d. Web. 10 Mar. 2013. <http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/encanas-backing-bolsters-case-for-natural-gas-export-terminal/article1947109/>.

"Venezuela - Wikipedia, the free encyclopedia." Wikipedia, the free encyclopedia. N.p., n.d. Web. 10 Mar. 2013. <http://en.wikipedia.org/wiki/Venezuela>.

Villar, Jose A. , and Frederick L. Joutz. The Relationship Between Crude Oil and Natural Gas Prices. Washington, DC: Energy Information Administration, Office of Oil and Gas , 2006. Print.

Wang, Ton-Lo Wang. "INFLUENCE OF HEAVY TRUCKS ON HIGHWAY BRIDGES."http://www.dot.state.fl.us/. Florida Department of Transportation, n.d. Web. 10 Mar. 2013. <www.dot.state.fl.us/research-center/Completed_Proj/Summary_STR/FDOT_379.pdf>.

"Washington County, PA - Official Website." Washington County, PA - Official Website. N.p., n.d. Web. 10 Mar. 2013. <http://www.co.washington.pa.us/>.

Washington, Suzanne. "Front: President for 60 more days, Bush tearing apart protection for America's wilderness: Oil shale mining in Rocky Mountains gets go-ahead:

'Midnight regulations' to dismantle safeguards. ." The Guardian [London] 8 Nov. 2008, Final ed., sec. Front Page: 1. Print.

"Water Management."http://www.askchesapeake.com. Chesapeake Energy, n.d. Web. 12 Feb. 2011. <www.askchesapeake.com/Barnett-Shale/Production/Pages/WaterManagement.aspx>.

"Water Use Fact Sheet."http://www.chk.com. Chesapeake Energy, n.d. Web. 11 Feb. 2011. <www.chk.com/media/educational-library/fact-sheets/corporate/water_use_fact_sheet.pdf>.

"Water Use in the Barnett Shale." The Railroad Commission of Texas. Texas Railroad Commission, n.d. Web. 10 Mar. 2013. <http://www.rrc.state.tx.us/barnettshale/wateruse_barnettshale.php>.

"Water recycling company's expansion plans include buying water from Brazos » Weatherford Democrat." Homepage » Weatherford Democrat . N.p., n.d. Web. 10 Mar. 2013. <http://weatherforddemocrat.com/homepage/x1155976014/Water-recycling-company-s-expansion-plans-include-buying-water-from-Brazos/print>.

"Welcome to Bradford County." Welcome to Bradford County. Bradford County, PA, n.d. Web. 9 Mar. 2013. <www.bradfordcountypa.org/>.

"Welcome to Fountain Quail Water Management, LLC." Welcome to Fountain Quail Water Management, LLC. N.p., n.d. Web. 10 Mar. 2013. <http://www.aqua-pure.com/>.

"West Texas Intermediate (WTI) Definition | Investopedia." Investopedia - Educating the world about finance. N.p., n.d. Web. 10 Mar. 2013. <http://www.investopedia.com/terms/w/wti.asp>.

"West Texas Intermediate - Wikipedia, the free encyclopedia." Wikipedia, the free encyclopedia. N.p., n.d. Web. 10 Mar. 2013. <http://en.wikipedia.org/wiki/West_Texas_Intermediate>.

"What Is a Shale Gas Play? | Eagle Ford Shale Blog." Eagle Ford Shale Maps and News Eagle Ford Shale Blog. N.p., n.d. Web. 10 Mar. 2013. <http://eaglefordshaleblog.com/2010/03/03/what-is-a-shale-gas-play/>.

Whitmer, Walt, and Kathy Brasier. "Marcellus Shale Exploration and Development: Organizing a Community Task Force." College of Agricultural Sciences Publications. N.p., n.d. Web. 8 Nov. 2010. <http://pubs.cas.psu.edu/PubTitle.asp?varTitle=marcellus&Submit=Go>.

Wilber, Tom . "Marcellus truck traffic not kind to Pa. roads." www.pressconnects.com. Gannett, 3 May 2010. Web. 9 Mar. 2013.

<www.pressconnects.com/article/20100503/NEWS01/5030372/Marcellus-truck-traffic-not-kind-Pa-roads>.

Williamson, Harold F., Ralph Andreano, Arnold R. Daum and Gilbert C. Kiose (1963). The American Petroleum Industry: The Age of Energy 1899-1959. Evanston, IL: Northwestern University Press.

Wood, Michael . "Testimony On the Natural Gas Severance Tax Proposal ." Pennsylvania House Appropriations Committee, Subcommittee on Fiscal Policy. Pennsylvania House Appropriations Committee. Pennsylvania House Appropriations Committee, Subcommittee on Fiscal Policy, Harrisburg. 6 June 2009. Speech.

Wright, Gavin , and Jesse Czelusta. "Stanford University." Mineral Resources and Economic Development . Version Feb. 2004. STANFORD CENTER FOR INTERNATIONAL DEVELOPMENT, n.d. Web. 9 Mar. 2013. <www.stanford.edu/group/siepr/cgi-bin/siepr/?q=system/files/shared/pubs/papers/pdf/SCID209.pdf>.

Zelio, Judy, and Lisa Houlihan. "State Energy Revenues Update." NCSL Home. N.p., n.d. Web. 10 Mar. 2013. <http://www.ncsl.org/default.aspx?tabid=12674>.