The Pennsylvania Marcellus Natural Gas Industry: Status, Economic Impacts and Future Potential

Timothy J. Considine, Ph.D.
Robert Watson, Ph.D., P.E.
Seth Blumsack, Ph.D.

July 20, 2011

The Pennsylvania State University
College of Earth and Mineral Sciences
Department of Energy and Mineral Engineering

Acknowledgements

The authors of this study acknowledge that the Marcellus Shale Coalition provided the funding for this study. Research support from the School of Energy Resources and the Center for Energy Economics and Public Policy at the University of Wyoming is also acknowledged.

Disclaimer

This report was prepared as an account of work sponsored by the Marcellus Shale Coalition. Neither the John and Willie Leone Family Department of Energy and Mineral Engineering at Penn State, the Center for Energy Economics and Public Policy at the University of Wyoming nor the Marcellus Shale Coalition, nor any person acting on behalf thereof, makes any warranty or representation, express or implied, with respect to the accuracy, completeness or usefulness of the information contained in the report nor that its use may not infringe privately owned rights, or assumes any liability with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report. This report was written and produced for the Marcellus Shale Coalition by the John and Willie Leone Family Department of Energy and Mineral Engineering, Penn State University. The opinions, findings, and conclusions expressed in the report are those of the authors and are not necessarily those of The Pennsylvania State University, The University of Wyoming, or the Marcellus Shale Coalition. To obtain additional copies of the report or with questions regarding the content, contact Timothy J. Considine at tconsidi@uwyo.edu or (307) 760-8400, or Robert Watson at rww1@psu.edu or (814) 234-2708.

Study Team

Timothy J. Considine, PhD – Dr. Considine is the School of Energy Resources Professor of Energy Economics and Director of the Center for Energy Economics and Public Policy in the Department of Economics and Finance at the University of Wyoming. Dr. Considine was formerly a Professor of Natural Resource Economics at the Pennsylvania State University from 1986 to 2008.

Robert W. Watson, PhD PE – Dr. Watson is Emeritus Associate Professor of Petroleum and Natural Gas Engineering and Environmental Systems Engineering in the John and Willie Leone Family Department of Energy and Mineral Engineering at the Pennsylvania State University. Dr. Watson is also the Chairman of the Technical Advisory Board to Oil and Gas Management of the Pennsylvania Department of Environmental Protection.

Seth Blumsack, Ph.D. – Dr. Blumsack is an Assistant Professor of Energy Policy and Economics in the John and Willie Leone Family Department of Energy and Mineral Engineering at the Pennsylvania State University.

Executive Summary

This study is the third in a series of reports (Considine, et al., 2009 and 2010) documenting the development of the Marcellus Shale and its economic impacts on the Commonwealth of Pennsylvania. This update finds that during 2010 Pennsylvania Marcellus natural gas development generated $11.2 billion in value added or the regional equivalent of gross domestic product, contributed $1.1 billion in state and local tax revenues, and supported nearly 140,000 jobs (see Table ES1).

Table ES1: Summary of Actual, Planned, and Forecast Economic Impacts

	Millions of 2010 Dollars				
Year	Value Added	State & Local Taxes	Employment	Wells Spudded	Output bcfe / day*
2009	4,703	573	60,168	710	0.3
2010	11,161	1,085	139,889	1,405	1.3
		Planned			
2011	12,844	1,231	156,695	2,300	3.5
2012	14,531	1,402	181,335	2,415	6.7
		Forecast			
2015	17,195	1,677	215,979	2,459	12.0
2020	20,246	2,003	256,420	2,497	17.5

* bcfe is billion cubic feet of natural gas equivalents per day.

Also during 2010, Marcellus production averaged 1.3 billion cubic feet equivalents (BCFE) per day of natural gas, which includes dry natural gas and petroleum liquids. Output at year-end 2010 from the Pennsylvania Marcellus was nearly 2 billion cubic feet per day. These production levels are substantially higher than our previous projections because Marcellus producers are employing advanced well stimulation techniques that are dramatically increasing well productivity.

Based upon our survey, Marcellus producers plan to spend significantly more in 2011 and 2012, generating more than $12.8 billion in value added in 2011 and another $14.5 billion during 2012 (see Table ES1). This higher economic activity generates almost $2.6 billion in additional state and local tax revenues during 2011 and 2012. Employment in the state expands to more than 156,000 jobs during 2011 and over 180,000 jobs during 2012. This dramatic increase in Marcellus drilling activity has occurred during a period of general economic recession and relatively low natural gas prices. Natural gas production from the Pennsylvania Marcellus will likely average 3.5 billion cubic feet per day during 2011 and could exceed 6 billion cubic feet per day during 2012. In addition, approximately 0.5 BCF per day of production is generated from conventional gas wells.

Pennsylvania is now self-sufficient in supplying itself with natural gas and in future years will likely become a major supplier of natural gas and liquids to consumers in other states. This study projects that Marcellus gas production could expand to over 17 *billion* cubic feet per day by 2020, which would make the Marcellus the single largest producing gas field in the United States, if real natural gas prices do not fall significantly. If this occurs, Marcellus economic activity could support over 250,000 jobs and generate $2 billion in annual state and local tax revenues.

As in our previous studies, these economic impacts are estimated based upon our survey of expenditures by Pennsylvania natural gas companies and an input-output model developed by the Minnesota IMPLAN Group, Inc. Input-output models are ideally suited to estimate the economic impacts of natural gas development because they completely capture business-to-business spending and how lease and bonus payments and royalties are spent by land owners and how this spending affects business activity. Exploring, drilling, processing, and transporting natural gas requires goods and services from many sectors of the economy, such as construction, trucking, steelmaking, and engineering services. Gas companies also pay lease and royalty payments to land owners, who also spend and pay taxes on this income. Higher energy production stimulates employment, income, and tax revenues.

The IMPLAN model has been used to estimate the economic impacts of development in other energy sectors, including a study by the Pennsylvania Department of Labor (2010) estimating the economic impacts of green jobs in renewable energy and energy efficiency. Input-output models have also been used in studies that estimate life-cycle environmental impacts of energy commodities, including natural gas (Jaramillo, et al., 2009) and Pennsylvania electricity production (Blumsack, et al., 2010).

The projections developed in this report depend upon the Pennsylvania Marcellus maintaining its relative competitive position. Currently, there are at least six other major shale gas plays competing for capital with the Marcellus, including the Barnett, Haynesville, Fayetteville, Woodford, Bakken and Eagle Ford formations as well as several shale formations in Canada. As production from these plays expands, prices for natural gas are likely to remain relatively low and pressures for cost containment will be intense. Gas development costs in Pennsylvania are relatively higher than other regions due to more regulations, harsher climate conditions, more challenging topography, higher labor costs and other structural factors. These higher costs, however, are partially offset by wholesale prices in Pennsylvania that are higher than the national average.

The development of the Pennsylvania Marcellus will have economic impacts beyond those measured in this report. If the Marcellus is developed to the extent envisioned in this report, the abundance of reliable, low cost natural gas could attract gas intensive manufacturing industries to expand capacity in Pennsylvania. Low cost natural gas also contributes to inexpensive electricity that enhances industrial development and economic growth. New industries would lead to additional gains in employment, output, and tax revenues. Finally, the Marcellus also could enable the use of compressed natural gas in transportation, improving environmental quality and reducing imports of foreign oil.

With rising levels of public debt, this ability to produce domestic energy while generating income and wealth is valuable. In summary, the development of the Pennsylvania Marcellus increases domestic energy production, creates jobs, and reduces government deficits.

Table of Contents

List of Tables

List of Figures

I. Introduction

This study provides an update of our two previous studies on the economic impacts of the Marcellus (see Considine, et al. 2009, 2010), presenting results from our latest survey of current and planned industry spending, analysis of the economic impacts of this activity, and projections of future drilling, natural gas production, and related economic impacts (Considine, et al., 2009, 2010). Unlike the previous studies, however, this report estimates the impact Marcellus production has on prices for natural gas and expenditures for natural gas and electricity in Pennsylvania. This report also presents an analysis of labor market and sales tax data that affirms the economic stimulus provided by the Marcellus industry. The evidence and analysis presented below indicates that the Pennsylvania Marcellus has emerged as a significant supplier of natural gas to the nation and a major source of jobs, income, and tax revenue for the Commonwealth of Pennsylvania.

For this study, we conducted a survey of producers to estimate drilling activity, spending levels, and production rates. The survey results clearly show a significant increase in activity, with total spending increasing from $3.2 billion during 2008, to nearly $5.3 billion during 2009, which is up from our previous 2010 estimate of $4.5 billion for 2009. Our survey results this year indicate that 2010 spending was $11.5 billion, which is also higher than the $8.8 billion producers planned to spend last year. The current survey finds that companies plan to increase their investment spending to $12.7 in 2011 and to over $14.6 billion in 2012. This evidence confirms that the Pennsylvania Marcellus industry in three short years has emerged as substantial industry in the Commonwealth and more broadly as a major producer of natural gas and petroleum liquids.

The survey and the findings of this report do not include historical or projected spending to upgrade interstate natural gas transmission pipelines, although it is recognized that Marcellus Shale development will result in significant new construction activity in that sector. Midstream investments that include gathering pipeline systems and gas processing facilities, however, are captured in our survey. This report does not consider development of several other organic shale formations that exist above and beneath the Marcellus nor does it measure investments by gas consuming industries induced by the availability of low cost Marcellus gas, such as, petrochemical, fertilizer, glass, and steel industries or investments in transportation systems using compressed natural gas.

Capital investments for Marcellus development have significant impacts on the economy of the Commonwealth of Pennsylvania. Producing natural gas requires exploration, leasing, drilling, and pipeline construction. These activities generate additional business for other sectors of the economy. For example, leasing requires real estate and legal services. Exploration crews purchase supplies, stay at hotels, and dine at local restaurants. Site preparation requires engineering studies, heavy equipment and aggregates. Drilling activity generates considerable business for trucking firms and well-support companies now based in Pennsylvania that in turn buy supplies, such as fuel, pipe, drilling materials, and other goods and services. Likewise, construction of pipelines requires steel, aggregates, and the services of engineering construction firms. Collectively, these business-to-business transactions create successive rounds of spending and re-spending throughout the economy. These higher sales generate greater sales tax revenues. Moreover, as businesses experience greater sales they hire additional workers. Greater employment increases income and generates higher income tax revenues.

Natural gas development also affects the economy through land payments. Natural gas companies negotiate leases with landowners to access land for development. These agreements often provide an upfront payment or bonus to oil and gas rights owner after signing the lease and then production royalty payments during the life of the agreement if production is established. In 2010 alone, natural gas companies paid over $1.6 billion in these lease and bonus payments to Pennsylvania landowners. After paying taxes, lease and bonus income recipients may save a portion or spend the rest on goods and services from other sectors of the economy. For example, a farmer may spend lease and bonus income to hire a carpenter to remodel a barn, who then buys lumber and supplies, and pays taxes on the net income earned from the project.

Economists have long recognized these indirect and induced impacts from capital investments and the development of new industries. Countless studies have been conducted on these types of economic impacts arising from the construction of sports stadiums, hospitals, highways, wind turbines, and other capital investments. Nearly all of these studies have been conducted using input-output (IO) models of the economy. Input-output analysis accounts for the flow of funds between industries, households, and governments. These models provide a snapshot of the structure of the economy at a point in time and, thereby, an empirical basis for addressing a variety of questions surrounding economic development. A typical input-output study might address the size of the workforce required to support a new industry or investment project. Input-output models are also commonly used in estimates of "life-cycle" environmental impact assessments for products and processes (Hendrickson, et al., 2006).

These questions are asked so frequently that the economic research and consulting firm called Minnesota IMPLAN Group, Inc. in association with the University of Minnesota has been in business since 1993 providing detailed IO tables at the county and state level. Indeed, a recent study conducted by the Pennsylvania Department of Labor and Industry (2010) used the IMPLAN system to estimate the number of jobs created in Pennsylvania through the expansion of green industries, including renewable energy and energy efficiency. The analysis presented below also uses the same IMPLAN model for Pennsylvania, finding that the $11.5 billion of spending by Marcellus producers during 2010 generated $11.2 billion in value added, $1.085 billion in state and local tax revenue, and almost 140,000 jobs.

The prospects for future Marcellus development in Pennsylvania are promising. For example, the spending planned by Marcellus producers in 2012 could generate more than $14 billion in value added, $1.4 billion in state and local tax revenues, and 180,000 jobs. After factoring in higher than anticipated productivity of Marcellus wells, our revised forecast suggests that the Pennsylvania Marcellus alone could be producing more than 17 billion cubic feet of natural gas per day by 2020.

Unlike conventional oil and gas development expanding production from shale resources requires continuous drilling activity. Substantial cutbacks in drilling significantly reduce production after a few years because the production decline curve is initially very steep for shale gas reservoirs. Nevertheless, the sheer geographical size of the Marcellus supports significantly higher levels of drilling. The forecast presented in this study estimates that nearly 2,500 wells could be drilled in 2020, which is down considerably from our previous forecast of 3,500 wells. This lower projection reflects our use of a smaller price elasticity of drilling activity that would be consistent with stable natural gas prices, as well as recognizing that longer lateral wellbores will be drilled than originally forecasted. If future natural gas prices rise substantially, additional drilling and production could occur because the resource base for the Marcellus is so large. Under a scenario where future natural gas prices rise and remain high, the large geographical area of the Marcellus could support more than 3,500 or more wells drilled annually.

With higher natural gas production from the Marcellus royalty income increases substantially. When combined with greater business activity from additional drilling, significant flows of value added and income for the state are created. Our estimates suggest that in 2020 the Marcellus industry in Pennsylvania could be creating more than $20 billion in value added, generating $2 billion in state and local tax revenues, and supporting more than 250,000 jobs. With rising levels of public debt, this ability to independently generate private income and wealth is essential.

These benefits depend upon the Pennsylvania Marcellus maintaining its relative competitive position. Currently, there are at least six other major shale gas plays competing for investment capital with the Marcellus, including the Barnett, Haynesville, Fayetteville, Woodford, Bakken and Eagle Ford shale plays as well as several shale formations in Canada. Oily shale plays such as the Eagle Ford and Bakken are particularly attractive given the historic price differential between dry gas and liquid hydrocarbons. As production from these plays expands, prices for natural gas are likely to remain relatively low and the pressures for cost containment will be intense. The economic literature has found that taxation of non-renewable resources does reduce exploration and production in a variety of economic environments (Yucel, 1986; Yucel, 1989; Deacon, French and Johnson 1990). In response to cost-containment pressures, some states have elected to reduce base severance tax rates during the first few years of production (examples include Texas, Arkansas, Oklahoma, and Louisiana). The absence of a severance tax in Pennsylvania along with city gate prices higher than the national average offsets higher costs associated with complex regulations, climate conditions, topography, higher labor costs, and other structural factors.

The next section of this report provides an overview of the emerging role of the Marcellus in national energy markets. Section three then describes the results from our survey of Marcellus producers operating in Pennsylvania. The fourth section of the report discusses the economic modeling methodology and the estimated impacts of Marcellus development on output, employment, and tax revenues during 2010. The impact of higher Marcellus production on natural gas prices and expenditures for natural gas and electricity in Pennsylvania and related economic impacts appear in section five. Recent trends in sales tax revenue and labor markets, presented in section six, provide additional empirical evidence for the economic stimulus provided by Marcellus investment. The seventh section of this report discusses the findings from our survey of investment spending in 2011 and 2012. Projections of the future level of development and related economic impacts appear in section eight. The study concludes with a summary of our major findings and a brief discussion of the implications for policies that affect the long-term health and vitality of the industry.

II. The Marcellus and National Energy Markets

The Marcellus Shale, as part of the larger domestic shale development, will likely play a significant role in the future as the U.S. economy seeks to expand domestic energy resources. The projections below envision a very significant expansion in Marcellus production in the years ahead. Historically, unconventional gas, such as shale gas, was considered a high cost source of supply. Advances in directional drilling and hydraulic fracturing along with large reserves, however, have contributed to falling average extraction costs for these resources.

Empirically estimating average and marginal extraction costs for the Marcellus industry is difficult because companies have negative cash flow during the early phase of development as wells gradually get connected to pipeline systems and produce marketable gas. Nevertheless, discounted cash flow analyses of individual Marcellus wells suggest the possibility of strong rates of return given drilling and gas gathering costs and, of course, market price, which is a key factor affecting the development of the Marcellus. Since natural gas prices are volatile, gas drillers and their customers may lock in a price with a futures contract.

As Figure 1 below illustrates, prices for natural gas in the United States have decoupled from crude oil prices. Prices for immediate and future delivery are a function of market conditions for natural gas. Among other factors, oil prices affect gas supply and demand. A substantial share of gas production is in association with oil production. In other words, they are co-products. As the price of oil goes up, companies drill for more oil, find it, pump it and along the way produce natural gas as the oil is extracted from the well. On the demand side crude oil prices affect prices of refined petroleum by-products, such as propane and ethane that directly compete with natural gas as an input in petrochemical production. As oil prices increase, petrochemical producers shift their mix of inputs away from propane to natural gas. Both of these channels tend to generate a positive relationship between prices for crude oil and natural gas. On the other hand, natural gas also competes with coal, nuclear, and renewable energy in the power generation market. The role of natural gas in generating electricity has increased substantially since the mid-1990s. Inter-fuel competition from the power generation sector tends to further confound the relationship between crude oil and natural gas prices.

Nevertheless, historically natural gas prices do track oil prices but with some notable departures and only rarely achieving parity with oil prices. Over the long term, natural gas prices have generally been below oil prices measured in heat equivalent units, known as British Thermal Units (BTUs). For example, over the sixty years period from 1922 to 1992, the year when natural gas markets were largely deregulated, oil prices averaged three times the price of natural gas. Much of this high differential was due to federal price controls on natural gas that caused the famous gas shortage in the winter of 1977-78, which eventually lead to total deregulation of gas prices (Considine, 1983). This ratio dropped to 1.5 from 1994 to 2008.

The relationship between natural gas and oil prices from 1994 through May 2011 is displayed in Figure 1. During the 1990s real natural gas prices averaged about $3 per million BTUs (MMBTU). Since then natural gas prices averaged more than $6.63 per MMBTU. Notice that the trend in oil prices was upward until the summer of 2008. After a sharp downward adjustment during the winter of 2008-2009, due to recessionary pressures oil prices recovered during the remainder of 2009 into 2011.

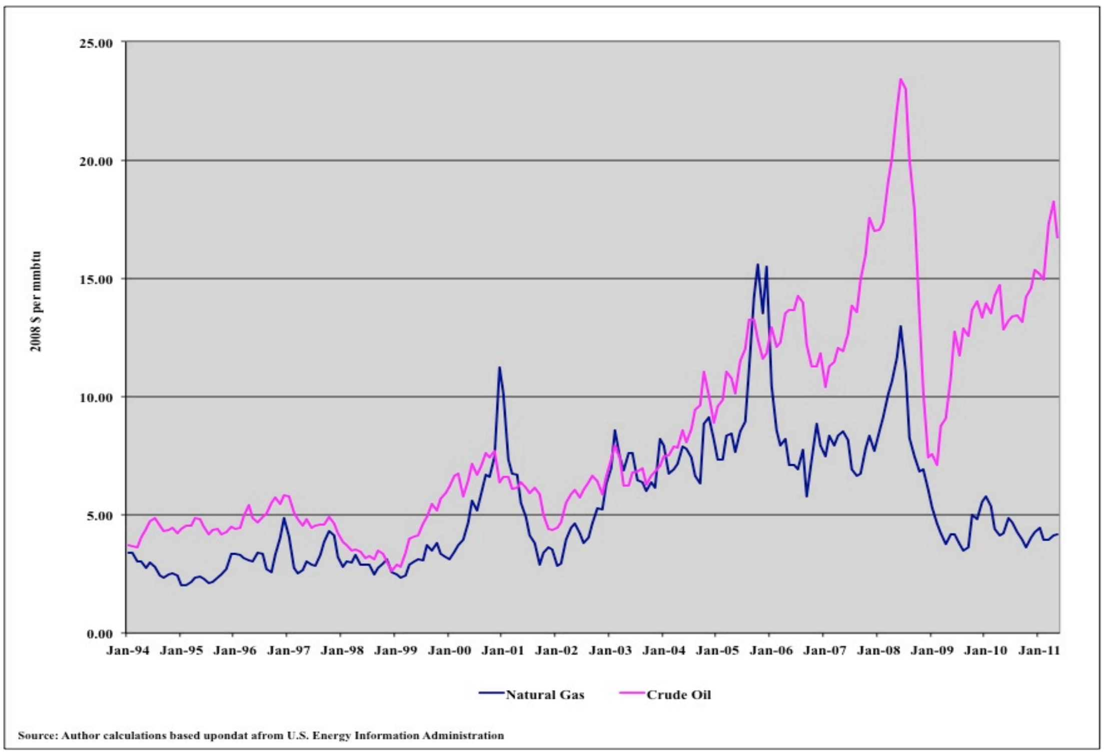

Figure 1: Real Natural Gas and Oil Prices in million BTUs, 1994-2010

Real natural gas prices, however, have remained low and are currently at levels last seen during 2002. One temporary factor is the sharp reduction in industrial gas consumption due to the recession. This pattern has been repeated in the past. Oil prices during 2006 and 2007 generally tracked upward and natural gas prices finally spiked during the summer of 2008 with the historic rise in oil prices. Nevertheless, apart from the oil price shock during the summer of 2008, natural gas prices have been drifting lower since 2005. The opening of unconventional shale gas resources is a contributing factor to this trend toward declining real natural gas prices.

Such a divergence between oil and natural gas prices has occurred in the past. Moreover, there are several factors contributing to a tenuous relationship. During the 1960s through 1980s natural gas competed with residual fuel in the boiler fuel and petrochemical markets. Residual fuel oil use in power generation has fallen substantially over the last decades. Many so-called "peaking" power generators are now duel-fueled, able to run on natural gas or refined petroleum products. Natural gas also competes with coal to provide "base-load" electricity in many regions of the U.S. The emergence of renewable electricity generation, particularly wind energy, also affects the natural gas market. In 2008, wind captured 42 percent of new power generation capacity added in the U.S., spurred by a mix of federal and state subsidies. In the Mid-Atlantic region, over 40 percent of planned generation investments through 2015 are wind energy, with much of the remainder consisting of new natural gas units. Natural gas power plants compete with renewables for investment dollars, but the flexibility of many natural gas power plants makes them ideal for providing "balancing" energy to the grid when wind energy production fluctuates.

Since the beginning of electricity deregulation in the early 1990s, most new electric power generation capacity has been based upon natural gas. Lower capital costs, shorter build times and strategic environmental considerations have contributed to this increased reliance on natural gas in power generation. Indeed, most of the growth in natural gas consumption has come from the electric utility sector (see Figure 2). In 2001, electric utilities consumed 14.6 billion cubic feet (BCF) per day. By 2010, they were consuming 20.1 BCF per day.

Another factor affecting market prices and the development of the Marcellus Shale is competition from other sources of natural gas. After reaching a peak in 1973 at 22.6 trillion cubic feet (TCF) U.S. natural gas production fell precipitously during the era of price controls in the 1970s, reaching a low of 16.8 TCF in 1983. Production then staged a steady recovery, reaching 20.6 TCF in 2001. Between then and 2005, however, U.S. natural gas production declined to 18.9 TCF. Expanding use of gas in power generation and declining production, contributed to rising prices during this period (see Figure 1).

Since 2005, however, U.S. natural gas production has increased at an average annual rate of 3.6 percent, increasing deliverability by 10.3 BCF per day or by over 19 percent. Production from federal offshore Gulf of Mexico and New Mexico declined 3.3 BCF per day. This means that production from other areas increased by 13.6 BCF per day. Of this increase, 3.5 BCF per day or 35 percent came from other states. The Pennsylvania Marcellus increased production more than 1 BCF per day during 2010. The Barnett field in Texas produced 3.6 BCF per day, followed by Louisiana at 2.6 BCF per day, which includes the Haynesville Shale, then by Wyoming at 1.9 BCF per day, and finally Oklahoma adding 0.5 BCF per day in natural gas production.

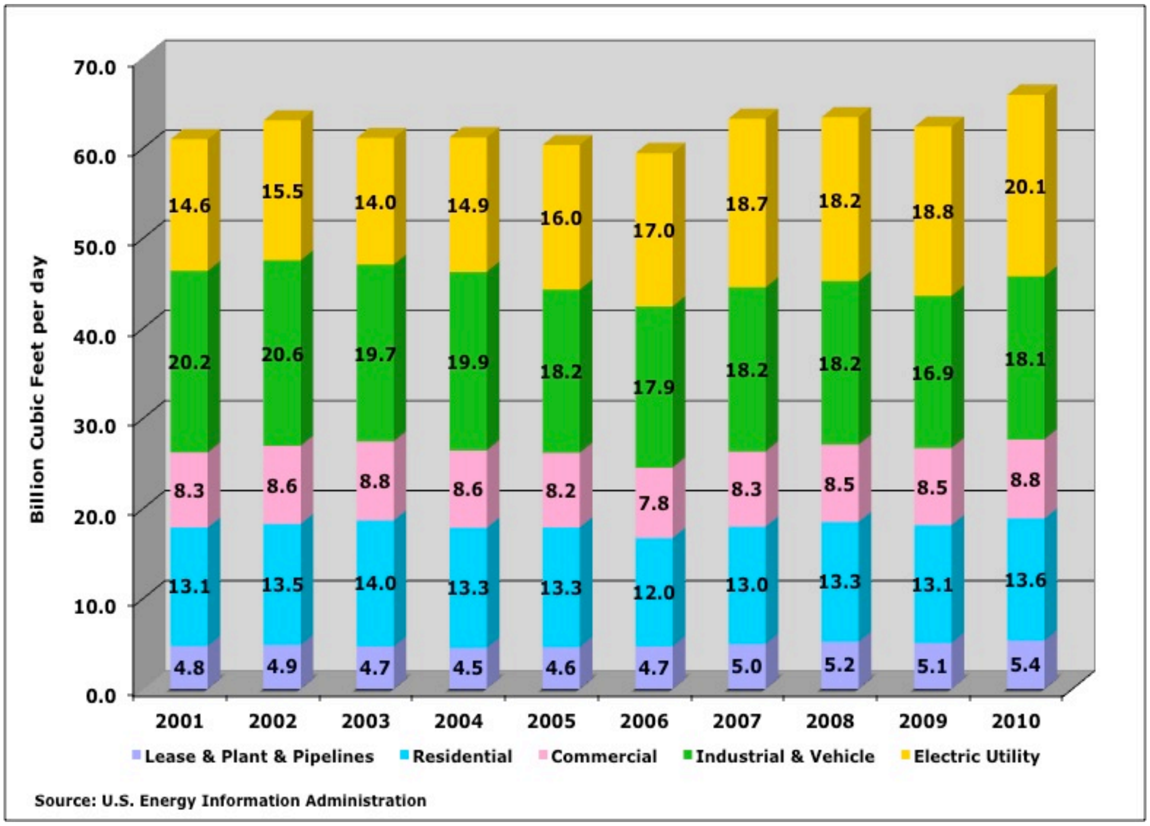

Figure 2: Composition of U.S. Natural Gas Consumption, 2001-2010

This is an encouraging development for the future of natural gas in our nation's energy supply portfolio because it demonstrates the potential of unconventional sources of natural gas. These supplies will be critical as production from shallow conventional onshore gas fields continue its inexorable decline.

Another implication of this supply picture is that several new sources of natural gas supply are emerging and likely will be in competition with the Marcellus play. This suggests that small margins in relative costs, as well as variations in natural gas prices may be important in determining the growth and vitality of these various sources of supply. Indeed, the slower pace of development of the Marcellus in West Virginia compared with the boom in Pennsylvania is in part a reflection of relatively higher costs in West Virginia.

Despite this supply-side competition, the Marcellus has some important advantages. The first competitive advantage is its proximity to a large regional natural gas market with significant future growth potential. Including Pennsylvania and its six bordering states, current natural gas consumption is 9.2 BCF per day. There is also a considerable amount of coal-fired electric power generation in this region, some of which will likely be retrofitted to burn natural gas as federal environmental regulations on point-source emissions become more stringent. If all planned natural gas power plants in the Mid-Atlantic region come on-line, this alone could increase regional natural gas demand by 1.5 to 2 BCF per day.[1] Thus, within a 200-mile radius of the Marcellus, the market for natural gas is highly likely to grow substantially. As detailed below, the Marcellus will likely become a significant supply source in future years, allowing plenty of room for market expansion. Of course, such an expansion will displace gas currently imported from the southwest and western U.S., which will have major ramifications for North American natural gas markets.

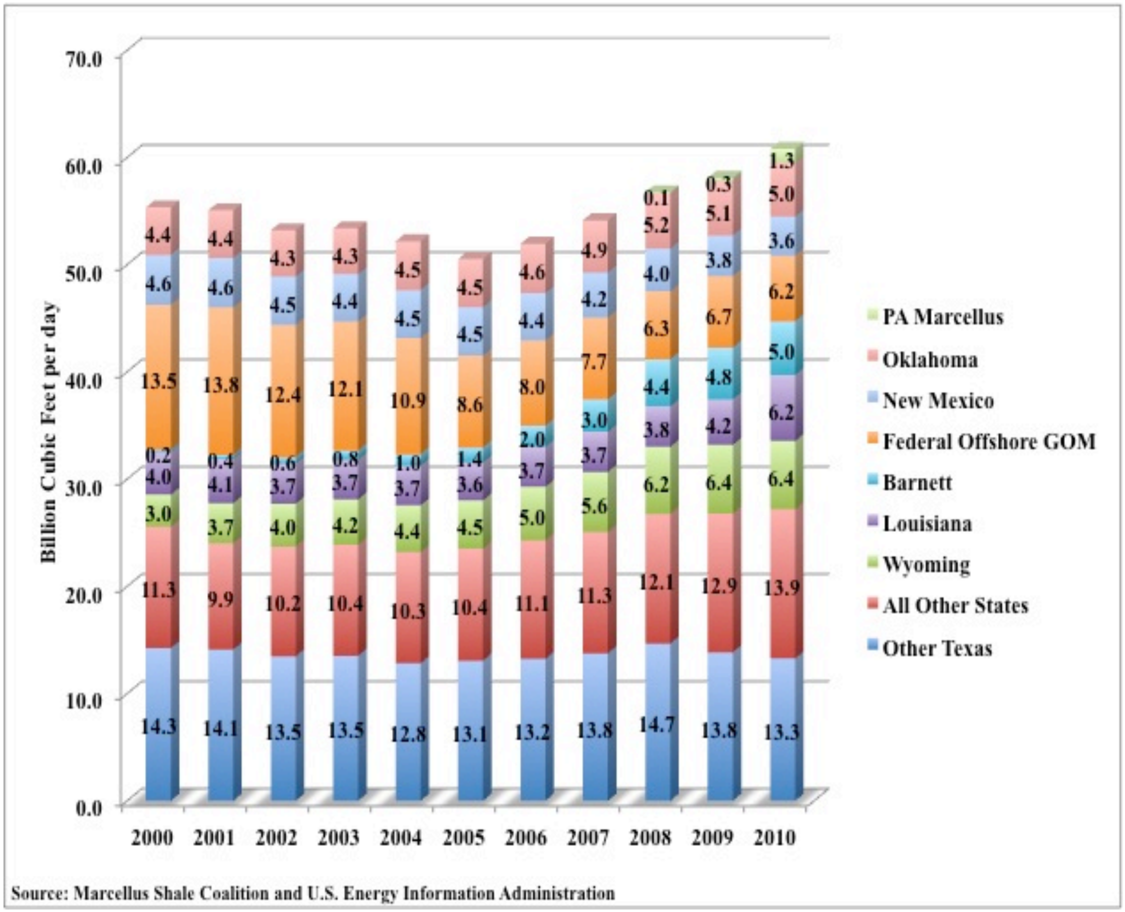

Figure 3: Regional U.S. Natural Gas Production, 2001-2010

Finally, another important market for the Marcellus is natural gas liquids, which originate from the wet gas producing area in southwestern Pennsylvania and in West Virginia. As Table 1 demonstrates, production of natural gas liquids increased almost 20 percent from 2009 to 2010 on the east coast of the United States, which includes the Pennsylvania Marcellus. There were also strong production gains in other regions, which bodes well for the U.S. trade balance.

[1] PJM's generation interconnection queue shows approximately 40 GW of new natural gas capacity. Assuming that this capacity has a duty cycle of 20% - 30% and average heat rates of 8,000 BTU/kWh, each GW of natural gas generation capacity would increase regional demand by approximately 15-18 BCF per year, or 1.6 – 2 BCF per day for all 40 GW of planned gas-fired generation.

Rising production of natural gas liquids from the Marcellus will be an important source for raw material requirements for the petrochemical industry in future years (American Chemistry Council, 2011).

Table 1: Field Production of Natural Gas Liquids

	Thousand barrels		Percent
	2009	2010	Change
East Coast	6,095	7,293	19.7%
Midwest	109,085	118,185	8.3%
Gulf Coast	372,269	385,481	3.5%
Rocky Mountain	97,954	108,941	11.2%
West Coast	12,817	11,761	-8.2%
United States	598,220	631,661	5.6%

Source: U.S. Energy Information Administration

III. Current Industry Activity

This project conducted a survey of natural gas producers operating in the Pennsylvania Marcellus. The survey form has three parts, a copy of the survey form is shown in Appendix A. The first set of questions sought to establish a baseline of economic and drilling activity with an estimate of total spending and wells drilled through year-end 2010. The second section asks for actual spending for 2009 and 2010 and planned spending for 2011-2012 for the following categories:

- Lease and bonus payments,
- Exploration,
- Upstream: drilling and completion,
- Midstream: pipeline and processing,
- Royalties, and
- Other goods and services.

The third and final section requested data on the number of rigs operating, wells drilled to total depth, and production of dry natural gas and petroleum liquids on a quarterly basis for 2010.

To determine the proportion of the industry represented by our sample, this project conducted a careful analysis of the inventory of wells started or "spudded" during 2010 as published by the Pennsylvania Department of Environmental Protection. Our analysis indicates that 1,405 wells were spudded during 2010 in Pennsylvania that could be verified as Marcellus Shale wells. A map of the wells drilled during 2010 appears below in Figure 1. Of the 1,405 wells spudded, 1,213 were horizontal and 189 were vertical wells. Like 2009, there again was a substantial increase in drilling activity in the northeastern counties of Susquehanna, Bradford, and Tioga with 723 wells drilled during 2010 up from 282 wells drilled during 2009 and 63 wells drilled during 2008. As Figure 4 below suggests, almost 85 percent of the wells drilled in these three northeastern counties were horizontal.

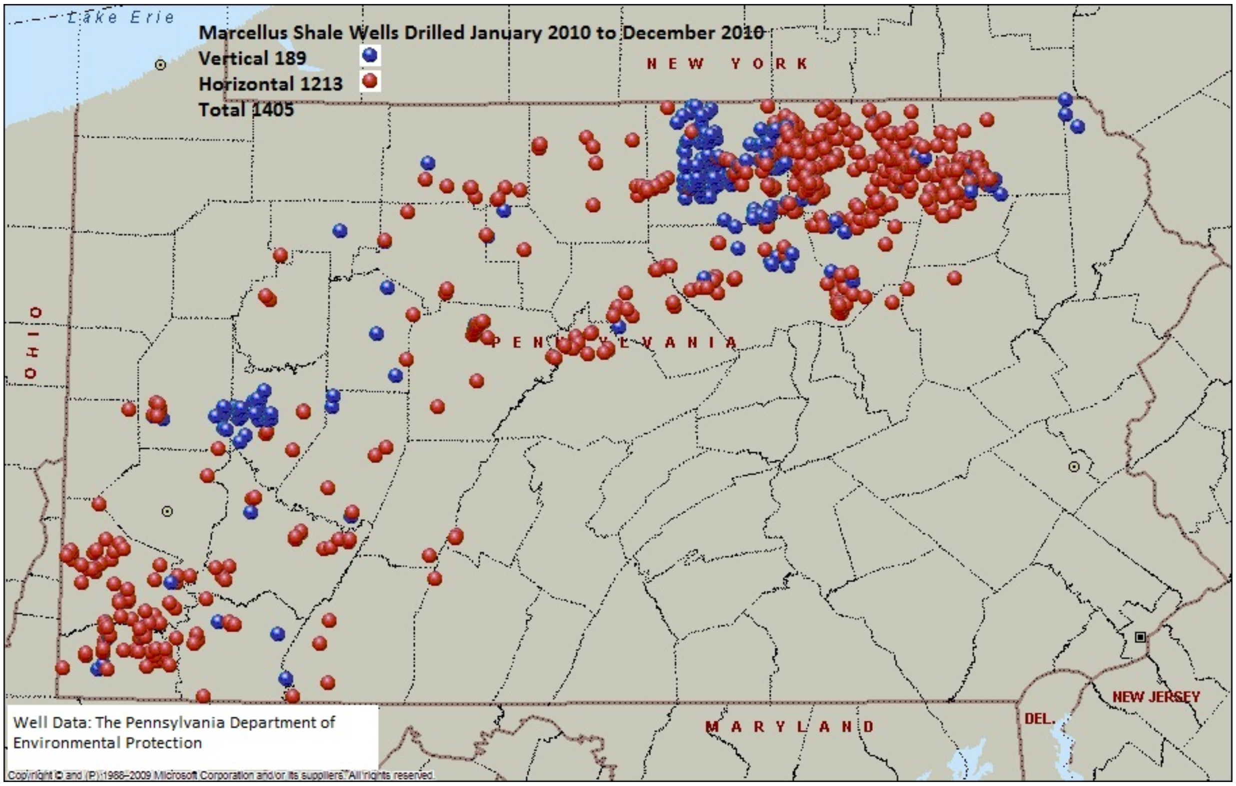

Figure 4: Marcellus wells started during 2010

Our survey was distributed to members of the Marcellus Shale Coalition in early February 2011. Responses from twelve firms were completed during June 2011. Based upon the well inventory analysis discussed above, these 12 firms drilled 770 wells, or more than 55 percent of the total wells started during 2010.[2] The ratio of total wells drilled to wells drilled by the companies participating in our survey is 1.82, which could be used to scale our sample estimates to estimate total industry activity. However, vertical wells comprised only 1.7 percent of the wells drilled by the companies participating in our survey this year. As a result, this study adopts a different approach by estimating industry well expenditures assuming $5.4 and $1.0 million per well for horizontal and vertical wells respectively and then dividing this by well expenditures for participating companies.[3] This results in a multiplier of 1.68, which is used to scale our sample to estimate the total size of the industry.

Given these assumptions, estimates of Marcellus industry spending for 2009 and 2010 based upon the 2011 survey appear in the last two columns of Table 2. Also included in Table 2 are the final estimates for Marcellus spending during 2008 and the preliminary estimates for 2009

[2] A total of 14 firms responded to the survey but two of those submissions were incomplete.
[3] These estimates are based upon Allowance for Expenditure (AFE) reports from selected companies.

based upon the 2010 survey. Our analysis this year suggests that Marcellus industry spending was higher than anticipated last year. For example, our survey last year estimated spending of $4.5 billion for 2009 whereas this year's survey indicates actual spending totaled $5.2 billion.

Marcellus industry spending more than doubled between 2009 and 2010 to $11.5 billion. Most of the increase came from higher expenditures on exploration, drilling, and pipeline and processing plant investments (see Table 2). Lease and bonus payments, which were the largest category at over $1.8 billion during 2008, increased to $2.17 billion during 2009 but then declined slightly to $2.06 billion during 2010. The largest expenditure category during 2010 is upstream drilling and completion of wells, which amounted to $7.377 billion during 2010 up from $2.15 billion during 2009. Mid-stream expenditures on pipelines and natural gas processing plants are the next largest category with over $329 million of spending during 2008, $695 million during 2009, and then $1.3 billion during 2010. The planned expenditures for the upstream and mid-stream segments of the industry discussed below will double yet again in 2011 and 2012. As previously mentioned, this report does not include expenditures for any "downstream" activities such as expansion of interstate natural gas transmission, increased natural gas compression capability, natural gas distribution or new businesses that may be created in Pennsylvania due to an abundant supply of reasonably priced natural gas.

Table 2: Marcellus spending in millions of nominal dollars, 2008-2010

	Final	Preliminary	Final	Preliminary
	2008	2009	2009	2010
Total Spending	3,224.6	4,535.3	5,283.9	11,477.1
Lease & Bonus	1,837.7	1,728.8	2,172.4	2,068.5
Exploration	121.9	243.8	117.1	208.4
Upstream: Drilling & Completion	857.8	1,700.4	2,151.0	7,377.0
Midstream: Pipeline & Processing	329.4	695.8	698.6	1,303.9
Royalties	22.2	54.7	53.4	346.0
Other	55.5	111.8	91.4	173.3

Not all of this spending occurred within Pennsylvania given that some supplies are imported from other regions and land income recipients may spend money outside the state. Our expenditure analysis based upon analysis of detailed accounting records from companies participating in our initial survey of 2009, however, indicated that 95 percent of this spending occurred within Pennsylvania. This indicates that a sizable well support industry has developed in Pennsylvania, particularly as corporations from the world oil and gas service business establish local headquarters in the Commonwealth.

Our survey asked producers for the number of rigs they were operating at the end 2009 and at the end of each quarter during 2010. The survey results appear below in Figure 5. At the end of 2009, 93 rigs were drilling in the Pennsylvania Marcellus (see Figure 5). By the end of the fourth quarter of 2010, the rig count rose to 129 (see Figure 2).

This increase in rig capacity translated to more wells drilled. Charted below in Figure 6, are wells drilled to total depth. At the beginning of 2010, 83 percent of wells drilled to total depth were horizontal wells and by the end of the year that percentage increased to 90% (see Figure 6). On average 12 wells were drilled per operating rig, which implies that each rig took 30 days to drill a well to total depth.

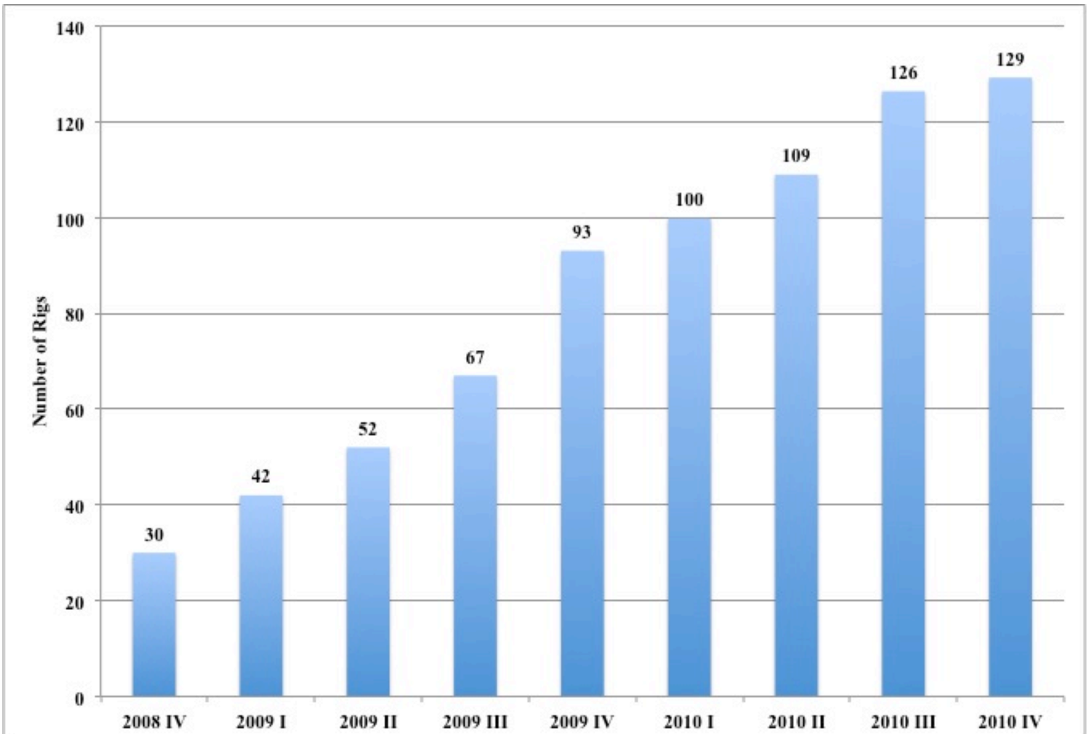

Figure 5: Marcellus Rigs operating in Pennsylvania by quarter, 2008-2010

The number of operating wells has also increased steadily since 2008, as shown in Figure 7. At the end of 2008, our previous sample suggested 280 wells were in production. One year later, 595 wells were operating and 1,055 wells were producing by the end of 2010 (Figure 7).

As these wells went into production, total natural gas production increased steadily. Figure 8 below reports quarterly average production of dry natural gas and natural gas liquids (NGL). During the last quarter of 2009, the Marcellus industry produced roughly 544 million cubic feet (mmcf) of natural gas and 6.8 thousand barrels of NGLs per day. As Figure 8 illustrates, total production accelerated sharply, exceeding 1.1 BCF per day by July and almost 2.0 BCF per day by the end of the fourth quarter of 2010. Over the same period, natural gas liquids production increased from 14.2 to 18.2 thousand barrels per day. Average annual production of dry natural gas was 311 and 1,353 million cubic feet per day during 2009 and 2010 respectively.

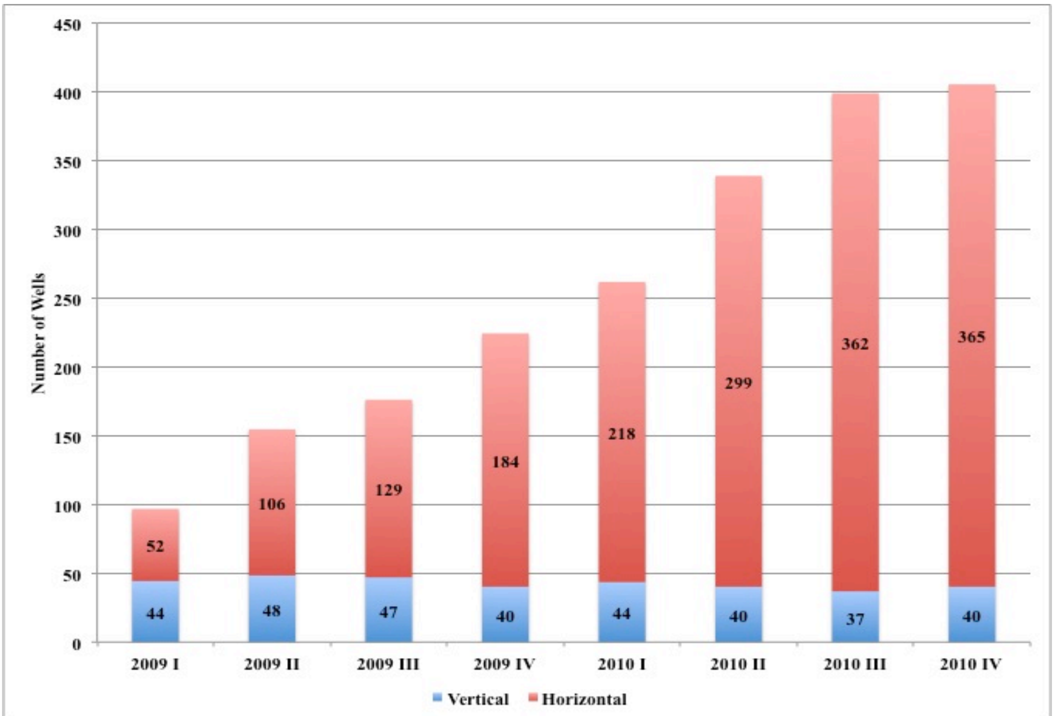

Figure 6: Marcellus Wells drilled to total depth 2009-2010

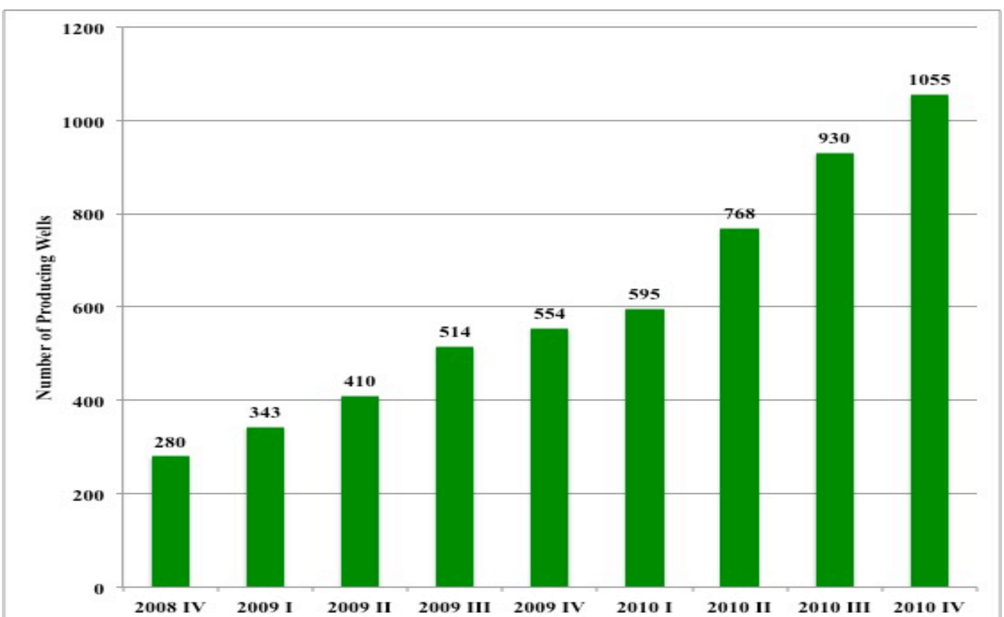

Figure 7: Marcellus wells producing in Pennsylvania, 2008-2010

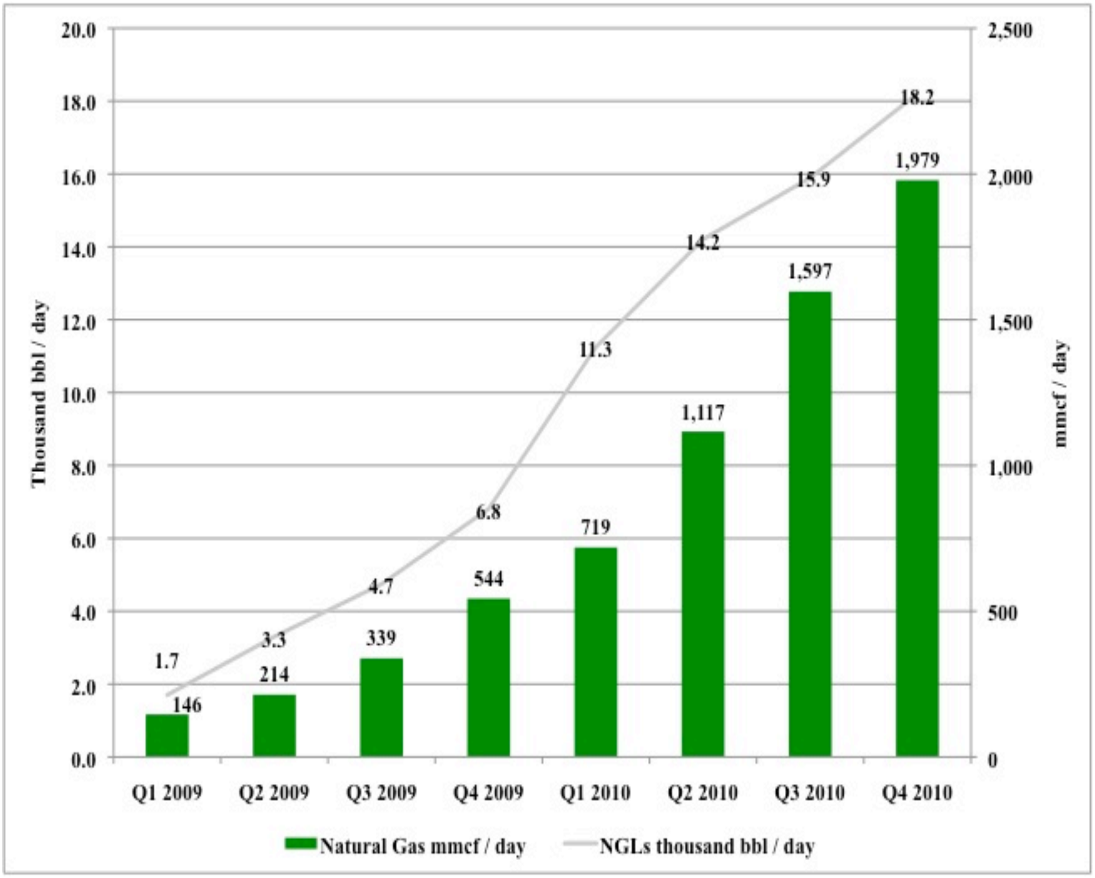

Figure 8: Quarterly production of natural gas and liquids

IV. Economic Impacts during 2010

While the drilling rig may be the most widely associated symbol of natural gas development, there are many activities before and after drilling that generate significant economic impacts. Many people are required to identify lease properties, write leases, and conduct related legal and regulatory work. Seismic surveys also require manpower, local business services, and other provisions. Once a prospective site is identified, site preparation and drilling begins and with it the need for services, labor, and other locally supplied activities. If natural gas is found in commercial quantities, infrastructure, such as well production equipment and pipelines are installed, which again stimulates local business activity. Finally, as production flows from the well, royalties are paid to landowners. These expenditures stimulate the local economy and provide additional resources for community services, such as health care, education, and charities.

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. For example, in developing mineral leases natural gas drilling companies employ the services of land management companies that in turn purchase goods and services from other businesses. These impacts are known as *indirect economic impacts*. The wages earned by these employees increase household incomes, which then stimulates spending on local goods and services. These impacts associated with household spending are called *induced impacts*. The total economic impacts are the sum of the direct, indirect, and induced spending, set off from the expenditures by Marcellus producers. These economic impacts are estimated by comparing gross output, value added, tax revenues, and employment in the local economy with and without Marcellus development.

Regional economic impact analysis using input-output (IO) tables and related IO models provide a means for estimating these economic impacts. Input-output analysis provides a quantitative model of the inter-industry transactions between various sectors of the economy and, in so doing, provides a means for estimating how spending in one sector affects other sectors of the economy. IO tables are available from Minnesota IMPLAN Group, Inc. based upon data from the Bureau of Economic Analysis in the US Department of Commerce.[4] This project uses these tables to estimate the economic impacts from the Marcellus industry outlays for natural gas exploration, development, and production. This study also identifies the specific economic sectors affected by the stimulus generated from natural gas development.

The Pennsylvania Marcellus is less than five years old and, therefore, is not included in the last update of the IO accounts for Pennsylvania available from IMPLAN. Accordingly, this study uses a technique proposed by Miller and Blair (2009) for introducing new industries into an input-output model of a regional economy. This approach requires estimating the input requirements of the new industry, which in our case are the purchases made by Marcellus gas producers from other sectors of the economy. Our previous report (Considine et al. 2009) collected detailed accounting data from Marcellus producers to determine these inter-industry transactions. The location of firms supplying inputs to Marcellus producers and their respective industrial sector codes were determined from business database directors. Our analysis in this report assumes that the nature of these inter-industry transactions has not changed since 2009.

Like our previous reports, this study estimates the direct, indirect, and induced economic impacts by sector using the IMPLAN model. This study did not involve collecting detailed accounting information. Instead, this analysis used the detailed information collected in the 2009 survey to link the data for spending categories above with the more disaggregated spending streams in the state level input-output system. In other words, the detailed data collected as part of the 2009 survey serves as a benchmark for our subsequent economic impact estimates. This benchmark approach is widely used by U.S. government agencies when they estimate economic activity

The first set of estimated economic impacts reported in Table 3 involves gross output, which is equivalent to gross sales. The Marcellus gas industry provides a direct economic stimulus of $10.4 billion dollars to the Pennsylvania economy. This spending then leads to subsequent rounds of spending and re-spending by other firms on goods and services, which adds another

[4] http://www.implan.com/index.html

$4.3 billion to total state gross output. These direct and indirect business activities generate additional income in the region, which *induces* households to purchase $5.7 billion in additional goods and services. The sum of these direct, indirect, and induced impacts is more than $20.46 billion in 2010.

These results imply that for every $1 that the Marcellus industry spends in the state, $2 of total economic output is generated. This estimate is considerably above the 1.34 multiplier found by Baumann et. al (2002) in their study of the impacts of oil and gas activities on the Louisiana economy. In a study of the economic impacts of the natural gas industry in New Mexico, Walker and Sonora (2005) assume an output multiplier of 1.43. The study by Snead (2002) finds an output multiplier of 1.55 for Oklahoma. This study's higher multiplier reflects our detailed expenditure analysis of benchmark-year 2008 data that allows direct measurements of inter-industry purchases.

Table 3: Impacts on Gross Output by Sector during 2010 in millions of 2010 dollars

Sector	Direct	Indirect	Induced	Total
Ag, Forestry, Fish & Hunting	35.4	17.8	14.4	67.6
Mining	3,534.4	246.0	10.6	3,791.0
Utilities	81.1	120.7	125.0	326.8
Construction	2,762.8	36.6	47.5	2,847.0
Manufacturing	222.8	731.8	371.5	1,326.2
Wholesale Trade	1,380.2	325.1	257.0	1,962.3
Retail trade	452.4	31.8	497.8	982.1
Transportation & Warehousing	252.1	284.4	133.2	669.7
Information	32.0	255.7	222.2	509.9
Finance & Insurance	62.1	377.7	712.9	1,152.7
Real estate & rental	298.5	369.1	1,016.2	1,683.8
Professional- scientific & tech services	534.7	808.3	246.5	1,589.5
Management of companies	0.0	241.3	59.4	300.7
Administrative & waste services	77.6	219.8	132.4	429.8
Educational services	116.6	3.4	136.3	256.3
Health & social services	258.8	3.6	1,015.0	1,277.4
Arts- entertainment & recreation	49.6	19.3	86.3	155.1
Hotel & food services	120.9	61.5	270.1	452.6
Other services	90.8	90.5	266.7	448.0
Government & Misc.	44.2	73.9	120.8	238.8
Total	10,407.1	4,318.5	5,741.8	20,467.4

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 (see Table 4). Using this measure, this study estimates that the Marcellus gas industry in Pennsylvania directly added over $5.3 billion to the economy of Pennsylvania, which then generated indirect and induced impacts that increased the total value added generated in the Commonwealth by $3.87 billion. In other words, the total economic impact of the Marcellus industry measured by valued added was $11.16 billion during calendar year 2010.

Table 4: Impacts on Value Added by Sector during 2010 in millions of 2010 dollars

Sector	*Direct*	*Indirect*	*Induced*	*Total*
Ag, Forestry, Fish & Hunting	10.6	6.9	4.7	22.2
Mining	1,311.3	94.0	5.7	1,411.0
Utilities	52.0	66.4	75.6	194.0
Construction	1,386.8	19.7	25.3	1,431.8
Manufacturing	66.2	211.5	93.0	370.7
Wholesale Trade	941.7	221.8	175.4	1,338.8
Retail trade	387.2	27.2	424.9	839.3
Transportation & Warehousing	128.5	155.6	69.9	354.0
Information	17.5	136.9	120.3	274.6
Finance & Insurance	36.2	218.1	410.4	664.7
Real estate & rental	212.2	257.9	722.2	1,192.3
Professional- scientific & tech services	356.1	527.9	174.1	1,058.1
Management of companies	0.0	156.6	38.5	195.2
Administrative & waste services	44.0	141.4	82.7	268.2
Educational services	67.6	2.0	82.4	152.1
Health & social services	151.7	1.9	582.4	736.1
Arts- entertainment & recreation	29.9	11.2	50.5	91.6
Hotel & food services	62.0	31.2	136.7	229.9
Other services	52.1	55.9	146.4	254.5
Government & Misc.	19.4	31.5	31.0	81.9
Total	5,333.0	2,375.5	3,452.3	11,160.8

Overall, the Marcellus gas industry generates a widespread increase in valued added across many sectors of the Pennsylvania economy. As Table 4 illustrates gains in value added from Marcellus industry spending exceeded $1 billion in five sectors: mining, construction, wholesale trade, real estate and trade, and professional scientific and technology services. Marcellus development generates value added in excess of $500 million in the retail trade, finance and insurance, health and social services industries. Gains in value added from the transportation, information, administrative services, other services, and hotel and food services sectors all exceed $200 million.

This broad increase in value added stimulates employment in many sectors of Pennsylvania's economy. The Marcellus industry purchases of goods and services, their royalties to landowners, and tax payments directly create more than 67,000 jobs in Pennsylvania. When indirect and induced impacts are considered, this study estimates that the total employment impact associated with Marcellus development amounts to almost 140,000 jobs (see Table 5), which represent the total number of jobs supported by the Marcellus industry.[5] The model estimates that 23,730 jobs have been created in construction trade, 16,581 in retail trade, 14,886 in mining, 12,815 in health and social services, 11,042 in professional services, 9,974 in

[5] Without royalties and lease and bonus payments, the total employment impact is 117,706.

wholesale trade, and 7,767 in hotel and food services. Like our estimated impacts on gross output and value added, these diverse job gains reflect the widespread stimulus to the Pennsylvania economy from the supply chain required to develop Marcellus Shale gas. These employment impacts are within the range reported in the literature. The results of this study indicate that for every $1 million of gross output created by natural gas production in the Pennsylvania Marcellus supports 6.8 jobs. This metric is within the range of employment multipliers of 3.0, 6.7, and 7.7 found by Walker and Sonora, Baumann et al., and Snead et al. respectively but more than the estimates reported by Perryman (2009) in a study of shale gas development in the Barnett Shale in Texas.

Table 5: Employment Impacts during 2010 in number of Jobs

Sector	*Direct*	*Indirect*	*Induced*	*Total*
Ag, Forestry, Fish & Hunting	318	253	208	780
Mining	13,663	1,181	42	14,886
Utilities	187	132	159	478
Construction	23,003	321	406	23,730
Manufacturing	450	1,790	695	2,936
Wholesale Trade	7,015	1,652	1,306	9,974
Retail trade	7,174	583	8,824	16,581
Transportation & Warehousing	1,709	2,127	1,028	4,864
Information	112	856	761	1,729
Finance & Insurance	257	1,798	2,932	4,986
Real estate & rental	870	1,940	2,550	5,360
Professional- scientific & tech services	3,209	6,009	1,824	11,042
Management of companies	0	1,057	260	1,318
Administrative & waste services	1,063	3,354	1,970	6,387
Educational services	1,406	45	1,954	3,405
Health & social services	2,772	27	10,016	12,815
Arts- entertainment & recreation	824	386	1,431	2,641
Hotel & food services	1,898	1,078	4,790	7,767
Other services	1,457	1,108	4,069	6,634
Government & Misc.	351	536	691	1,577
Total	67,739	26,234	45,916	139,889

The higher economic output and greater employment by the Marcellus gas industry generate additional tax revenues for federal, state and local governments. These impacts are reported below in Table 6. State and local tax revenues for Pennsylvania increase to slightly over $1.084 billion in 2010 with the bulk of the increase coming from indirect business taxes of $802 million. Federal taxes paid by Pennsylvania increase by $1.44 billion from Marcellus development with most of the increase coming from higher social security taxes and personal income taxes paid as more people are working and receiving income. The Allegheny Conference (2009) found that Pennsylvania's pre-Marcellus oil and gas industry in total generated $7.1 billion in economic impacts. Oil and gas producers drilled a total of 4,189 wells in Pennsylvania during 2007. Hence, according to their estimates every well drilled generates $1.7 million in economic impacts. In contrast, our study finds that each Marcellus well generates $6.2 million in economic impacts. This difference reflects the higher cost of Marcellus wells and the greater resource requirements for the supply chain.

Table 6: Tax Impacts during 2010 in millions of 2010 dollars

			State and Local Taxes			
Description	***Employees***	***Proprietor***	***Business***	***Households***	***Corporations***	***Total***
Dividends					52.19	52.19
Social Insurance						
Employee Contr.	3.56					3.56
Employer Contr.	8.84					8.84
Indirect Business						
Sales			327.10			327.10
Property			351.31			351.31
Motor Vehicle Lic.			7.07			7.07
Other			95.43			95.43
S/L Fees			21.60			21.60
Corporate Profits					33.22	33.22
Personal Income						
Income				148.43*		148.43
Fines & Fees				22.54		22.54
Motor Vehicle Lic.				6.85		6.85
Property				3.51		3.51
Other (Fish/Hunt)				3.29		3.29
Total State & Local	12.40		802.51	179.34	85.41	1,084.93
			Federal Taxes			
Social Insurance						
Employee Contr.	371.41	65.97				437.38
Employer Contr.	365.09					
Indirect Business						
Excise			58.65			58.65
Custom Duty			18.98			18.98
Fed Fees			50.35			50.35
Corporate Profits					121.66	121.66
Personal Income				386.81		386.81
Total Federal	736.50	65.97	127.98	386.81	121.66	1,438.92

* Adjusted to reflect the exclusion of lease and bonus payments from local income taxes
Assessed property values are unaffected by land payments. Real estate taxes show up as indirect business taxes because households pay the real estate sector.

V. Economic Impacts from Lower Natural Gas Prices

The Pennsylvania Marcellus has emerged as a major producer of natural gas in the United States. Higher levels of drilling but most importantly much higher-than-expected well productivity, is driving this surge in natural gas output. This study finds that this production growth likely will continue with major ramifications for national and international natural gas markets. To estimate how the Marcellus is affecting the price for natural gas and electricity, this study develops and estimates energy demand models for Pennsylvania. Lower prices for energy act like a tax cut for households and businesses, stimulating job creation and economic growth. In the years ahead as Marcellus production grows, developing new markets for natural gas both domestically in power generation and transportation and internationally in the form of liquefied natural gas (LNG) for export will be increasingly important for Marcellus producers, for the economy of Pennsylvania, and for the environment. This study lays the groundwork for quantifying the economic and environmental implications of demand side developments affecting the Marcellus industry.

The forecasting framework is built upon two modeling perspectives. First, the end-use demand for fuels in the residential, commercial and industrial sectors are modeled from an economic perspective in which energy demand is a function of relative prices, population and the level of economic activity. On the supply-side for electricity, however, an engineering-economic perspective is adopted in which capacity, utilization rates and heat rates are specified exogenously, with the exception of electricity generation from natural gas, which is determined as the difference between demand and other generation sources. Hence, natural gas is modeled as the swing fuel, which is consistent with the recent past in Pennsylvania. In most economic evaluations of alternative energy systems, such as solar, wind and biomass, natural gas prices are used as the basis for comparison. In other words, the opportunity cost of electricity from these new technologies is the avoided cost of electricity produced from natural gas.

The forecasting model determines electricity supply, demand and prices, given exogenous assumptions for primary fuel prices, economic growth, inflation and capacity expansion plans (Considine and McLaren, 2008). A schematic of the line of causality between these assumptions and the endogenous variables is presented below in Figure 9. End-use electricity demands and net electricity exports determine electric power generation requirements, which then drive the consumption of fuels in power generation. Generation capacity, operating rates and heat rates of operating units determine the composition of fuel consumption by electric utilities and the average cost of electricity generation. Retail electricity prices are calculated by adding transmission and distribution charges to average generation costs.

As Figure 9 illustrates, carbon emissions are tracked for each sector of the economy. The carbon tracking provides a nearly complete accounting of carbon dioxide equivalent emissions in the Pennsylvanian economy. Carbon emissions, therefore, are endogenous and depend upon energy prices and economic activity driving energy demand and the choice of electricity generation capacity. The feedback of final electricity demand on the demand for fuels and end-use electricity prices allows an integrated evaluation of electricity demand and fuel choice in power generation.

There are five main components of the model. The first three include systems of energy demand equations for the residential, commercial and industrial sectors. The fourth involves the demand for transportation fuels, including gasoline and diesel fuel. The fifth and final component involves the electricity generation sector. Appendix B describes the formulation of the models within each of these components.

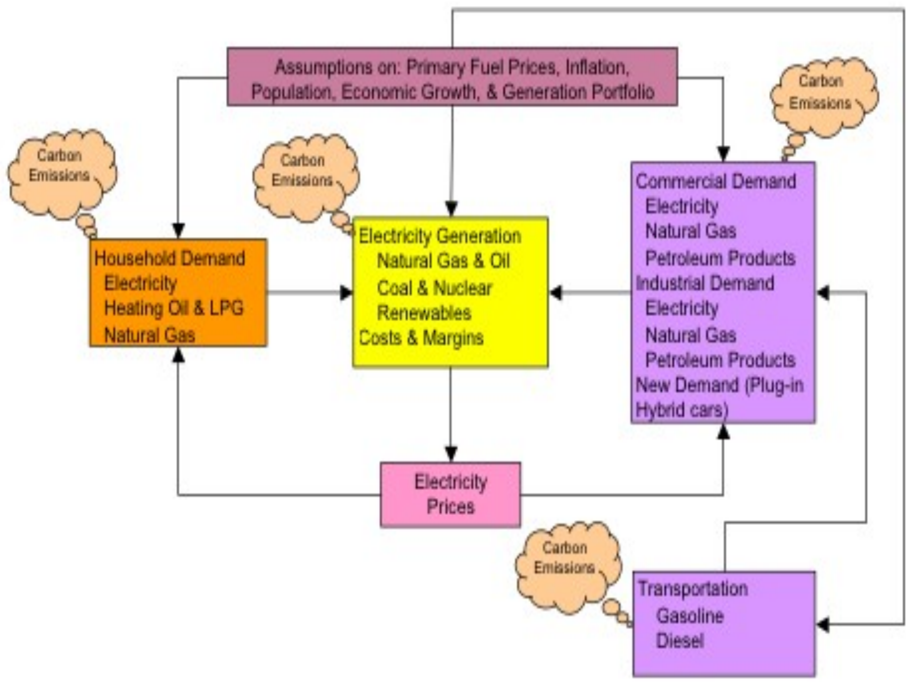

Figure 9: Overview of Energy Demand Model for Pennsylvania

As mentioned above, total U.S. natural gas production increased by 964,705 mmcf or 4.47 percent from 2009 to 2010. Of this increase, the Pennsylvania Marcellus contributed 380,453 mmcf, or 39.4 percent of the total increase in supply. Hence, the percentage change in supply attributed to the Marcellus is the product of Marcellus share and the total change in supply or 1.76 percent. To simplify the analysis, this study assumes that natural gas supply in the short-run is perfectly price inelastic or insensitive to price within a short period of time, such as one year. Given this assumption, the impact of higher Marcellus supply on prices for natural gas is determined by dividing 1.76 by the price elasticity of demand for natural gas in the short-run, which the econometric analysis presented in Appendix B finds is -0.14. This implies that the increase in Marcellus natural gas production during 2010 reduced natural gas prices by 12.6 percent from what they would have been without Marcellus production.

This reduction in natural gas prices reduces consumer outlays for natural gas and leads to lower electricity prices to the extent that natural gas is used to generate electricity. Once deregulation of electricity is complete, the study by Kleit et al. (2011) suggests that natural gas prices may emerge as a key driver for wholesale electricity prices for electricity. Lower electricity and natural gas prices have an income effect on consumer demand, which essentially stimulates consumer spending for other goods and services. Moreover, lower prices for natural gas and electricity reduce energy expenditures made by business and state and local government offices. The estimates of these expenditure reductions due to higher Marcellus output appear below in Table 7. Given a 12.6 percent reduction in natural gas prices due to higher Marcellus output, total energy expenditures declined by $633 million during 2010. In other words, without the Marcellus consumers would be paying more than $633 million in additional energy costs. Residential customers or households have electricity and natural gas bills that are $245.1 million lower as a result of gas production from the Marcellus with $217.4 from lower natural gas bills and another $27.7 million from lower electricity bills. Commercial and industrial customers pay $190 and $198.3 million less as a result of Marcellus production gains.

Table 7: Reductions in Energy Expenditures in Pennsylvania during 2010

	Millions of 2010 dollars		
	Electricity	Natural Gas	Total
Residential	27.7	217.4	245.1
Commercial	44.5	145.5	190.0
Industrial	51.1	147.3	198.3
Total	123.3	510.2	633.4

From the household perspective, reductions in energy expenditures act like a tax cut for the Pennsylvania economy, increasing discretionary income. There is some evidence from the economics literature to support this view; studies of oil price dynamics suggest that decreases in consumption and employment following energy price increases are matched by increases in consumption and employment once energy prices decline (Davis and Haltiwanger, 2001; Edelstein and Kilian, 2009). The impacts on other sectors of the economy are more difficult to model. Lower natural gas prices may simply increase profits of businesses. On the other hand, lower natural gas prices could increase the competitiveness or output of the Pennsylvania economy by attracting new business to re-locate in the Commonwealth. The extent of the increase in profits versus the expansion in output depends upon the elasticities of supply and demand for gas intensive goods and services. Unfortunately, there is very limited information on these elasticities. As a result, this study assumes that lower energy expenditures by the commercial and industrial sectors flow to profits and thereby have no secondary impacts on the local economy. The reduction in household energy expenditures is modeled as an increase in household income categories based upon IMPLAN data on expenditures for energy by income class.

From the household perspective, these reductions in energy expenditures stimulate the Pennsylvania economy, increasing valued added by another $170 million, state and local taxes by $18 million, and adding another 2,200 jobs to the impacts discussed in the previous section (See Table 8).

Table 8: Economic Impacts from Lower Energy Expenditures

	Millions of 2010 dollars		
Scenario	Value Added	State & Local Taxes	Jobs
Base Forecast 2010	11,160	1,085	139,889
2010 with lower prices	11,330	1,103	142,146
Changes	+170	+18	+2,257

VI. Economic Impacts in Perspective

The estimated economic impacts are model derived, specifically from the IMPLAN system. Actually observing jobs and value added created by Marcellus activity, however, is problematic because other events are affecting the economy at the same time. In this section we examine evidence from employment and sales tax data collected by Pennsylvania state government. These data provide additional perspective on the results of our economic impact modeling.

As of April 2011, Pennsylvania had an average seasonally adjusted unemployment rate of 7.5%, which was 1.5% below the national average of 9.0% as reported by the Bureau of Labor Statistics. To investigate the link between the Marcellus drilling activity and lower unemployment rates we compared the changes in unemployment rates by county to the state average unemployment rates on a monthly basis over a four-year period, since 2008.

Roughly half of the counties in Pennsylvania have some level of Marcellus drilling activity but it is the counties in which there is high drilling activity that the reduction in unemployment rate is most apparent and measureable. Plotted below in Figure 10 are differences in unemployment rates from the statewide average for six counties with the largest number of Marcellus wells drilled. During 2007, five of the six counties had unemployment rates above the statewide average. By 2011, four of the six counties had unemployment rates below the statewide average. For example, Bradford County had an unemployment rate of 8.33% in 2007 but by the end of April 2011 it had an unemployment rate of only 5.95%.

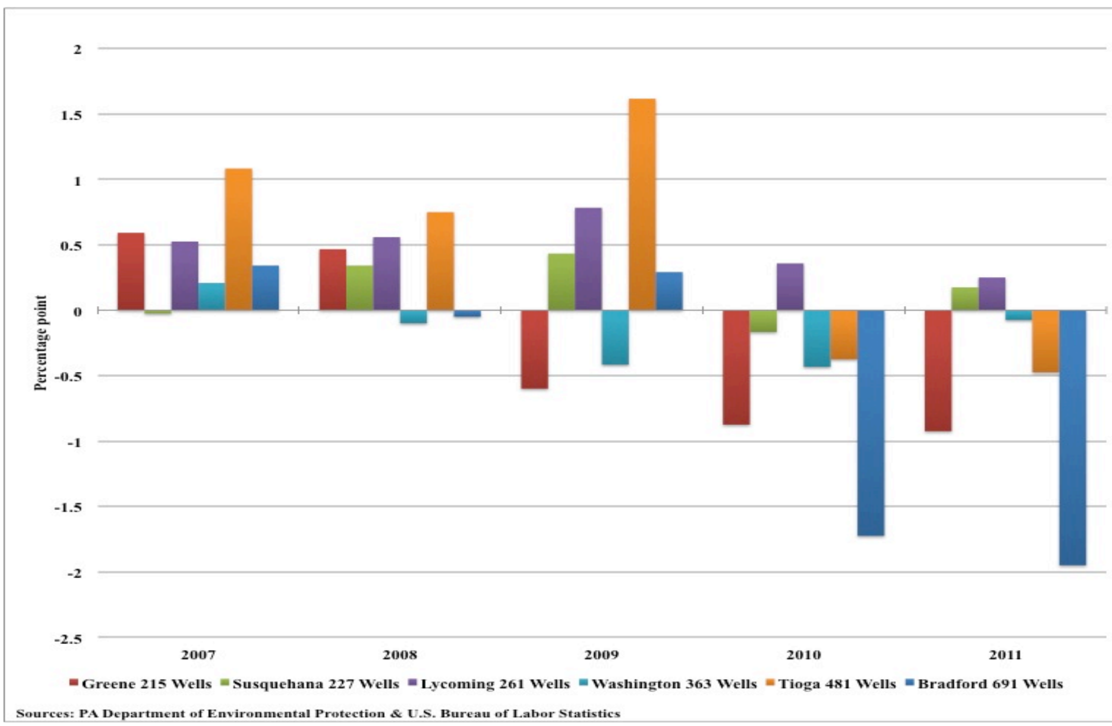

Figure 10: Unemployment rate differences from state average for Marcellus counties

Figure 11 illustrates the total wells drilled in the Marcellus and the average monthly difference in each county from the Pennsylvania statewide monthly unemployment rate in 2011. The areas in green represent counties that fell below the statewide average and those in orange were above the average. As this map illustrates, a large amount of the total drilling for the state is occurring in the northeastern region. These counties have also in turn seen the greatest relative reduction in unemployment rates.

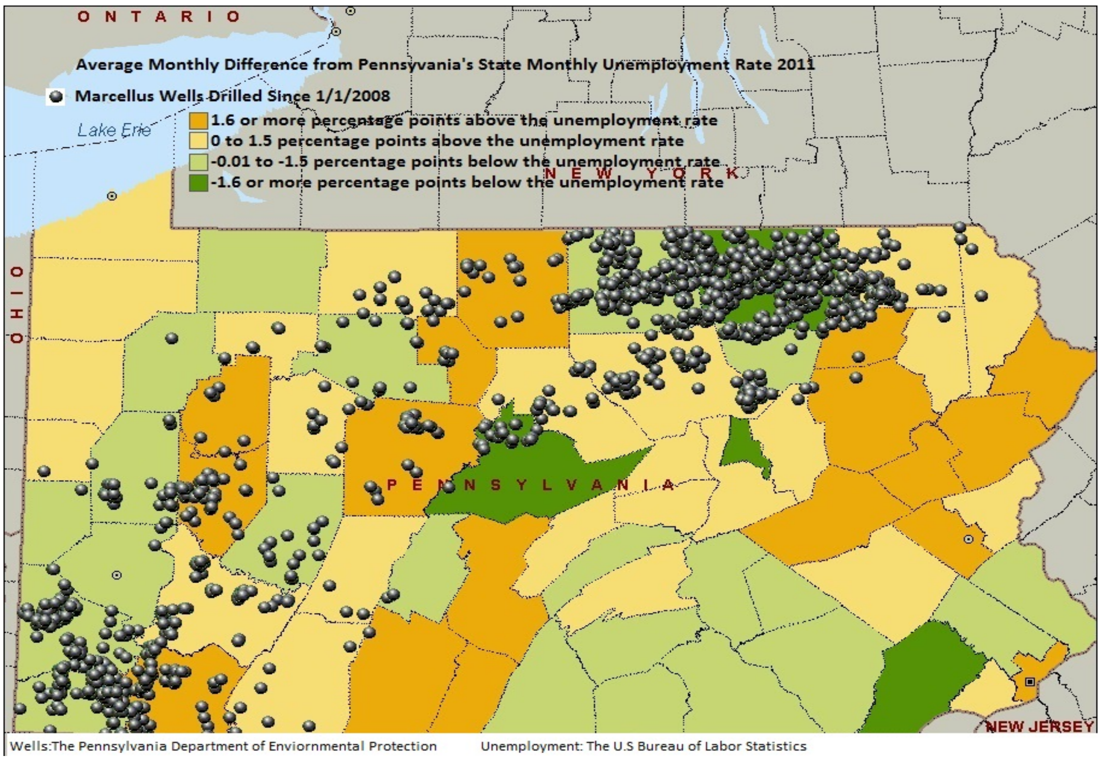

Figure 11: Unemployment rates and drilling by county

Sales tax revenue is another useful economic indicator, as it gauges the general commerce of the region in a way other metrics cannot. Unemployment rates, for example, can be somewhat limited for comparative purposes because many people that work in the natural gas industry do not live close to where the drilling is occurring. Pennsylvania imposes a 6% sales tax on all non-essential items including lodging so transient workers will almost inevitably add extra revenue to a local economy. With the large number of workers required for shale gas production this means significant additional sales tax revenue can be generated. The areas in which there is heavy drilling activity have seen a higher positive change in tax revenue. For example, from 2009 to 2010 Bradford County saw an increase in tax revenues of 13.22%, while the state as a whole saw tax revenues decline (on average) by 2.26%.

Figure 12 illustrates this point by comparing the average statewide sales tax revenue with counties grouped by the number of wells that have been drilled in the Marcellus. For counties with no Marcellus drilling, sales tax revenue declined 2.5 percent from 2008 to 2010. For counties with up to 100 Marcellus wells, sales tax revenue declined only 0.6 percent. Finally for counties with more than 100 wells drilled, sales tax revenue actually increased 0.6 percent (See Figure 13). The relationship between sales tax increases and high levels of drilling activity are most apparent in northeastern Pennsylvania. Overall, recent trends in labor markets and sales tax revenues support the results from the model simulations of the economic impacts using IMPLAN. Marcellus industry spending significantly stimulates economic activity, creating jobs and generating additional tax revenues.

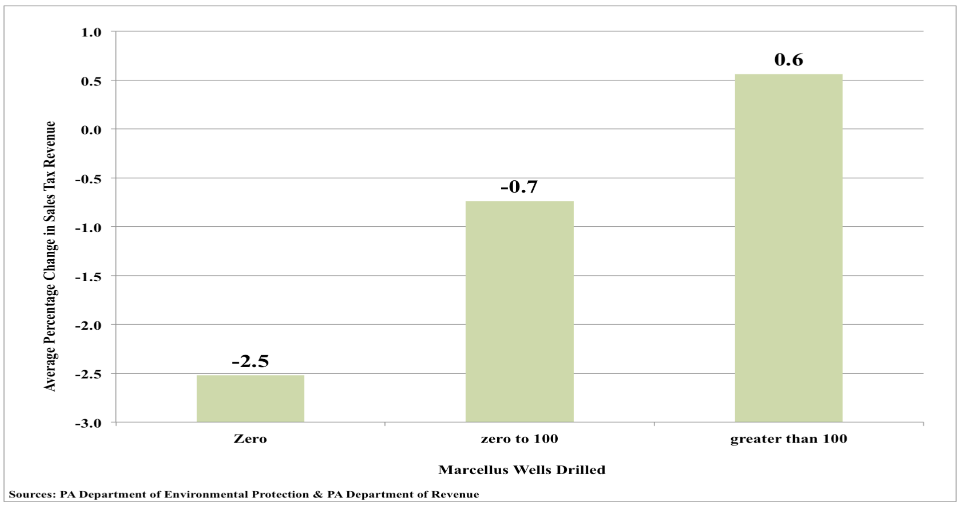

Figure 12: Sales tax revenue growth and drilling, 2008-2010

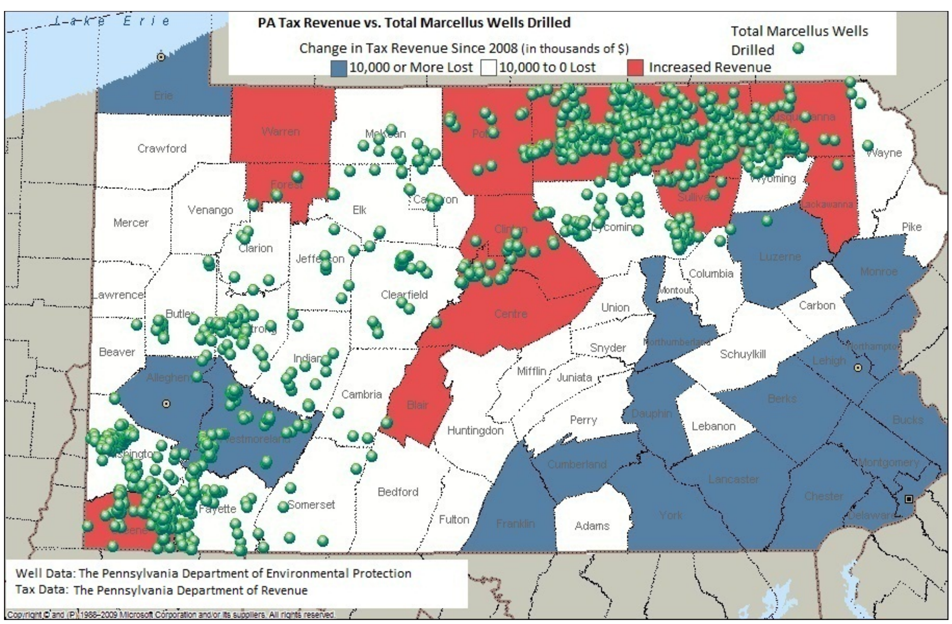

Figure 13: Sales tax revenue growth and drilling by county, 2008-2010

VII. Planned Industry Spending and Economic Impacts for 2011 and 2012

The survey asked Marcellus natural gas producers operating in Pennsylvania for estimates of planned industry spending for 2011 and 2012, which are reported below in Table 9. Producers plan to spend more than $12.7 billion during 2011. Overall, total planned spending for the next two years is up substantially from plans last year. Lease and bonus payments, however, decline sharply from $2.068 billion in 2010 to $759 million and $481.6 million in 2011 and 2012 respectively. Drilling and pipeline construction spending more than offset these reductions rising from $8.6 billion in 2010 to $10.6 billion in 2011 and over $12 billion in 2012. Royalty payments are also expected to rise from $346 million during 2010 to $735 million in 2011 and $1.86 billion during 2012.

Table 9: Planned Marcellus Spending in thousands of nominal dollars, 2010-2010

	Prelim.	***2010 Survey***		***2011 Survey***	
	2010	***2010***	***2011***	***2011***	***2012***
Total Spending	11,477.1	8,773.7	11,010.6	12,732.6	14,647.8
Lease & Bonus	2,068.5	1,602.2	1,577.7	759.0	481.6
Exploration	208.4	493.9	487.0	143.3	167.1
Drilling & Completion	7,377.0	4,468.3	6,489.8	8,295.1	9,294.6
Pipeline & Processing	1,303.9	1,785.9	1,586.3	2,633.8	2,768.4
Royalties	346.0	252.5	633.1	734.7	1,863.0
Other	173.3	171.0	236.7	166.7	73.0

The economic impacts from this planned spending are likely to be significant. To estimate these possible impacts, this study ran the IMPLAN model for Pennsylvania for these two years, adjusting for the effects of inflation. Below in Table 11 is a summary of the total economic impacts on value added and employment by sector. Value added from the Marcellus gas industry is $12.8 billion in 2011 and over $14.5 billion in 2012, while lease and bonus payments are expected to decline over this same period as the Pennsylvania Marcellus industry shifts to a higher-production phase.

Higher gross state product implies greater employment. For example, our estimates suggest that planned spending by the Pennsylvania Marcellus industry could support nearly 160,000 jobs in the state during 2011 and well over 180,000 during 2012 (see Table 10). As a result of higher real output and employment, state and local tax revenues could be $1.2 and $1.4 billion higher during 2011 and 2012 respectively. In short, the Marcellus shale gas industry adds true, real value to the Pennsylvania economy and in the process creates jobs and improves the fiscal health of the Commonwealth.

Table 10: Value Added and Employment Total Impacts from Planned Spending

	Value Added in Millions of 2010 Dollars		Number of Jobs*	
Sector	2011	2012	2011	2012
Ag, Forestry, Fish & Hunting	25.3	28.8	872	999
Mining	1,747.6	1,914.1	18,445	20,199
Utilities	210.8	244.8	531	610
Construction	1,768.6	1,939.4	29,315	32,144
Manufacturing	418.5	477.6	3,359	3,810
Wholesale Trade	1,618.0	1,791.2	12,053	13,344
Retail trade	906.5	1,055.8	17,781	20,780
Transportation & Warehousing	415.4	465.8	5,703	6,399
Information	308.8	353.1	1,935	2,217
Finance & Insurance	743.7	852.2	5,608	6,411
Real estate & rental	1,266.8	1,486.9	5,645	6,653
Professional- scientific & tech services	1,261.8	1,405.1	13,159	14,658
Management of companies	229.7	257.3	1,551	1,737
Administrative & waste services	309.8	349.9	7,388	8,340
Educational services	144.2	178.8	3,302	4,050
Health & social services	779.4	916.3	13,586	15,963
Arts- entertainment & recreation	91.6	110.6	2,678	3,214
Hotel & food services	235.8	281.4	8,044	9,557
Other services	270.6	317.5	6,989	8,237
Government & Misc.	90.8	104.5	1,749	2,012
Total	12,843.7	14,531.3	159,695	181,335

* Number of jobs represents estimated direct, indirect, and induced jobs during each year that result from Marcellus activity in Pennsylvania

VIII. Forecasts of Marcellus Industry Activity and Economic Impacts out to 2020

As the above analysis demonstrates, the economic impacts of the Marcellus gas industry are driven by inter-industry spending to support drilling activity and payments to land owners. As the Marcellus is developed, royalties will dominate payments to land owners, as the planned spending estimates presented illustrate for 2012. Therefore, to project future royalties a forecast of natural gas production is required.

Natural gas production in any period is the sum of production from current and all previous vintages of producing wells. The production profile of typical shale wells entails a rather sharp initial decline in the production rate and after a few years a much slower rate of decline. The production decline curves used in this study are depicted below in Figure 14, starting out with 3.6 BCF of estimated ultimate recoverable reserves (EUR) and gradually increasing to 4.6 BCF EUR by 2020, reflecting industry advances in recovery technology. Given this decline curve, average annual production from a Pennsylvania Marcellus horizontal well is over 650 mmcf during the first year, about 300 mmcf during the second, after 8 years about 130 mmcf, and roughly 40 mmcf per year after 30 years of production.

As the discussion above demonstrates, not all wells drilled in the Marcellus are horizontal. Vertical wells have a similar decline curve but substantially lower output. Accordingly, this study assumes that annual production from a vertical Marcellus well is slightly less than 15 percent of the output from a horizontal well.

Bottlenecks in infrastructure development are another feature of the industry that must be considered in projecting future production. There are widespread reports of producers drilling wells and then capping them until pipeline infrastructure can be built to carry the gas to market. Given time lags in constructing pipeline gathering systems and connections to major interstate pipeline networks, this study assumes a one-year lag between the time a well is drilled and when it is producing marketable gas.

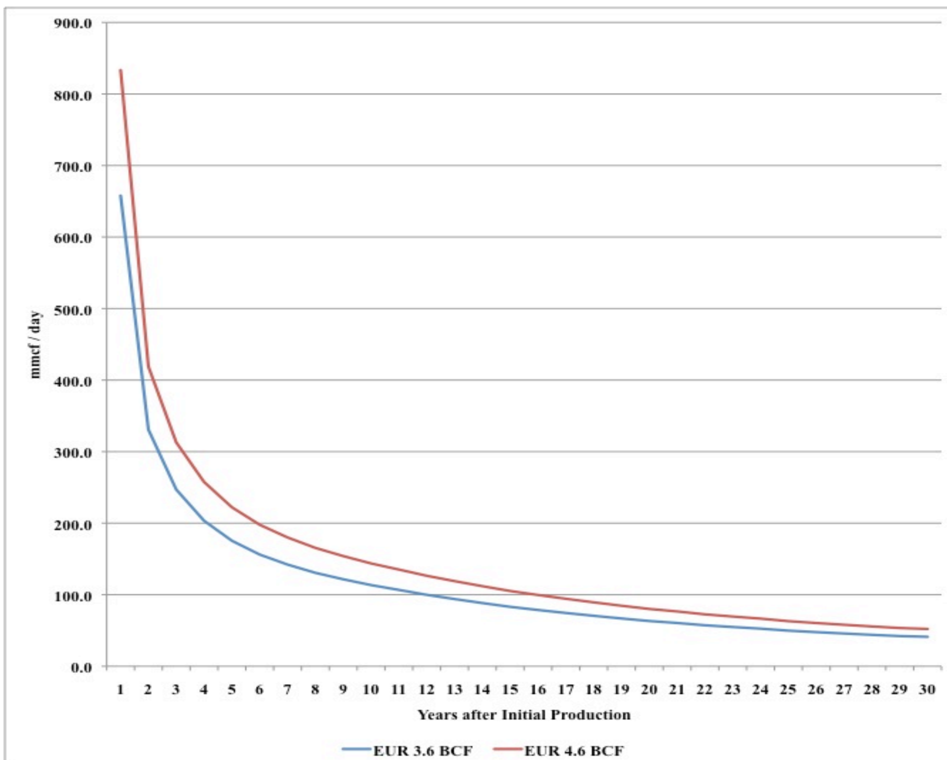

Figure 14: Production decline curves

Based upon the pace of drilling thus far from January through April, over 2,300 wells could be drilled during 2011. This study projects future drilling as a function of real natural gas prices assuming a price elasticity of drilling equal to unity for 2012 and 0.25 thereafter. The prices used in this study are futures prices for natural gas from the New York Mercantile Exchange reported on June 2011 adjusted for inflation. These inflation-adjusted prices in 2010 dollars are \$4.58 per thousand cubic feet (mcf) in 2012 and gradually increase to over \$5.30 per mcf by

2020. The current forward curve for natural gas is consistent with a scenario where increases in natural gas production are roughly matched with increases in consumption. We also assume that vertical wells will remain at 10 percent of total wells drilled through 2020. Given these assumptions, our projections of future Marcellus gas drilling and production are displayed below in Figure 14. Drilling activity increases from 2,415 wells drilled during 2012 to almost 2,500 wells drilled during 2020 (see Figure 15).

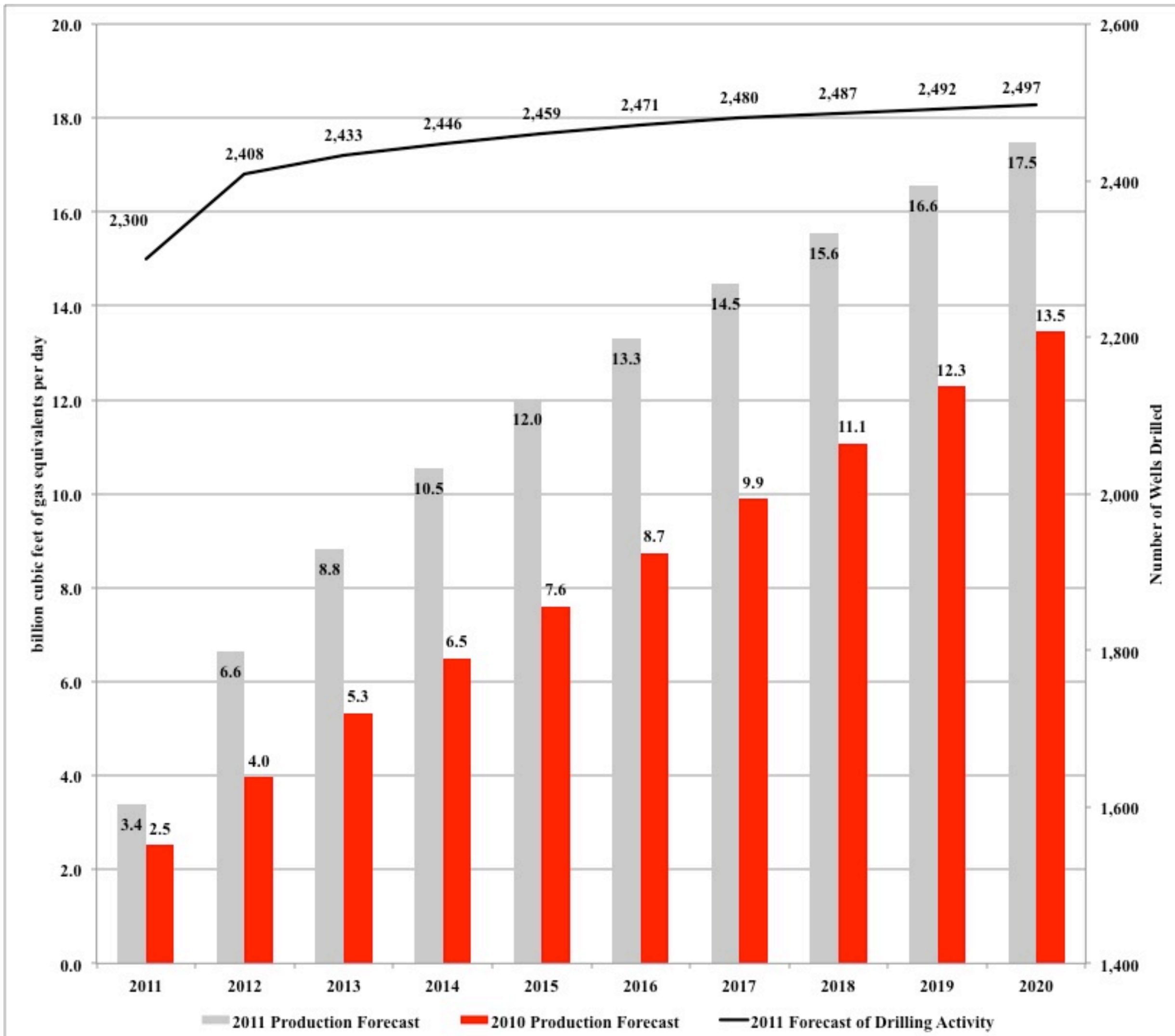

Figure 15: Forecast for Marcellus Drilling and Production, 2011-2020

Following recent trends, this study assumes that the share of vertical wells in total well drilled will remain at 10 percent through 2020. Given this and previous assumptions, this study projects a trajectory of natural gas production for the Pennsylvania Marcellus that is displayed above in Figure 14. Given planned drilling during 2011, production could exceed 3.5 bcf per day by 2011, substantially exceeding Pennsylvania's natural gas consumption and making the

Commonwealth a significant natural gas exporter. Pennsylvania could be producing over 12 billion cubic feet of gas per day by 2015 and upwards of 17 bcf per day by 2020, which would make Pennsylvania the second largest producer of natural gas behind Texas. As Figure 14 illustrates, the projections in this study are substantially higher than the projections made in last years report primarily due to higher-than-expected well productivity.

These projections are, of course, subject to a number of uncertainties. Excess supply or demand for natural gas will affect the forward price curve for natural gas and, thus change the economic attractiveness of additional drilling. Federal or state regulatory policies can affect drilling, production or environmental compliance costs for the Pennsylvania Marcellus industry. Other uncertainties may make our projections seem conservative. First, the productive capacity for a typical Marcellus well could be greater than indicated by the type curve used in these projections. Second, the level of drilling could be substantially higher than the levels projected here. At 2,500 wells by 2020, drilling density would remain quite low compared to other shale gas plays. If these projections are borne out, the Pennsylvania Marcellus could have a profound effect on the U.S. natural gas market.

This study estimates that future drilling and development activity will significantly stimulate the Pennsylvania economy. These projections of economic impacts assume a 15 percent average royalty rate and Marcellus investment spending that increases at a 2.3 percent rate in nominal terms on from 2013 to 2020. This study assumes that lease and bonus payments gradually decrease in nominal terms from their planned levels of $481 million in 2012 to $150 million in 2020. These latter two assumptions are conservative. Marcellus costs could rise more than 2.3 percent per year. Moreover, producers could make more lease and bonus payments because considerable Marcellus acreage remains open for leasing.

Given these assumptions, estimates of the future economic impacts are summarized in Table 11. During 2015, the Marcellus gas industry could be generating more than $17 billion in value added, $1.6 billion in state and local tax revenues, and supporting more than 215,000 jobs. In 2020, the projected impacts grow even larger with more than $20 billion in value added, $2 billion in state and local tax revenue, and a Marcellus-supported workforce of 250,000.

Table 11: Forecast Economic Impacts

	Millions of 2010 Dollars		
	Value Added	State & Local Taxes	Jobs
2015	17,195	1,677	215,979
2020	20,246	2,003	256,420

IX. Summary and Conclusions

This study provides updated estimates of the impacts of the Marcellus gas industry on the economy of the Commonwealth of Pennsylvania. This update was accomplished by conducting a survey of natural gas producing companies drilling the Marcellus play in Pennsylvania. Our survey results reveal that the industry spent nearly $11.5 billion on Marcellus development during 2010. By the end of 2010, our estimates suggest that there were more than 1,055 producing Marcellus wells in Pennsylvania producing almost 2 billion cubic feet of natural gas per day, which exceeds consumption of natural gas in Pennsylvania.

Our estimated economic impacts for 2009 and 2010 are substantially higher than estimates from last year. The estimates for total spending in 2009 increased from $4.5 billion last year to $5.3 billion this year. During 2010, the Marcellus gas industry increased Pennsylvania's value added by $11.2 billon, generated $1.1 billion in state and local taxes, and contributed to nearly 140,000 jobs.

Our survey also asked Marcellus natural gas producers how much they planned to spend for 2011 and 2012. Based upon the results from this survey, the near term outlook for the Marcellus gas industry in Pennsylvania is even more robust than we anticipated last year. Based on these spending plans, the Marcellus industry in Pennsylvania could generate more than $12.8 billion in value added during 2011. This economic activity would generate more than $1.2 billion in state and local taxes and support over 156,000 jobs (see Table 12). The rate of growth tapers somewhat in 2012. Nonetheless, the economic impacts are impressive with nearly $1.4 billion in additional tax revenues for the state and over 180,000 jobs.

Looking beyond the planning horizon and employing some conservative assumptions about drilling and production profiles, the outlook for Marcellus production is remarkable. By 2015, the Pennsylvania Marcellus could be producing over 12 billion cubic feet per day, second only to Texas in natural gas production. Marcellus natural gas production could reach 17 BCF per day 2020. The economic impacts of this level of production are very significant, dramatically improving the economic health of the Commonwealth of Pennsylvania and transforming the state into a major exporter of natural gas.

Table 12: Summary of Estimated, Planned, and Forecast Economic Impacts

Millions of 2010 dollars			
Year	Value Added	State & Local Taxes	Jobs
2009	4,703	573	60,168
2010	11,161	1,085	139,889
		Planned	
2011	12,844	1,231	156,695
2012	14,531	1,402	181,335
		Forecast	
2015	17,195	1,677	215,979
2020	20,246	2,003	256,420

Large-scale development of the Marcellus is reshaping the economic landscape of Pennsylvania. Strategies and policies that encourage growth of the Marcellus gas industry will generate significant economic and environmental benefits for the Commonwealth of Pennsylvania, transforming the Pennsylvania to a net natural gas exporter while creating hundreds of thousands of jobs and generating billions of dollars in additional output, income, and tax revenues.

There may be additional economic impacts not estimated in this report. The availability of low cost natural gas supplies, as well as NGLs, could stimulate the expansion of manufacturing capacity in the Commonwealth of Pennsylvania, such as steel, glass, foundries, chemicals, fertilizers, and other natural gas intensive industries. Such an expansion would further stimulate the supply chain and generate additional employment and tax revenue gains.

Despite its enormous potential, the Marcellus continues to compete for scarce investment capital with other shale plays around North America. Policies that raise the costs of developing the Marcellus relative to these other shale plays could reduce Marcellus investment, job creation, and tax revenue growth. Our analysis shows that the Pennsylvania Marcellus can promote domestic production of cleaner energy sources while providing a major stimulus to economic growth.

References

Allegheny Conference (2009) "The Economic Impact of the Oil and Gas Industry in Pennsylvania," Allegheny Conference on Community Development, June.

American Chemistry Council (2011) "Shale Gas and New Petrochemicals Investments: Benefits for the Economy, Jobs, and US Manufacturing," Economics and Statistics, March, 27 pages.

Apt, J., S. Blumsack and L.B. Lave (2007), "Competitive Energy Options for Pennsylvania," report for the Team Pennsylvania Foundation, available at http://wpweb2.tepper.cmu.edu/ceic/papers/Competitive_Energy_Options_for_Pennsylvania.htm.

Baumann, Robert H., D.E. Dismukes, D.V. Mesyanzhinov, and A.G. Pulsipher (2002) "Analysis of the Economic Impact Associated with Oil and Gas Activities on State Leases," Louisiana State University Center for Energy Studies, Baton Rouge, La. 11 pgs.

Blumsack, S., P. Jaramillo, W.M. Griffin and H.S. Matthews (2010), "Life Cycle Greenhouse Gas Inventory of Electricity Generation in Pennsylvania," report for the Pennsylvania Department of Environmental Protection.

Considine, T.J., R. Watson, R. Entler, J. Sparks (2009) "An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play," The Pennsylvania State University, Dept. of Energy and Mineral Engineering, August 5, 39 pages.

Considine, T.J. (1983) Natural gas wellhead pricing policies: Implications for the federal budget, Congressional Budget Office, April 1983, 1-53.

Considine and D. McLaren, (2008) "Powering Arizona: Choices and Trade-Offs for Electricity Policy," The Communications Institute, June, 34 pgs.

Davis, S. and J. Haltiwanger (2001) "Sectoral Job Creation and Destruction Responses to Oil Price Changes," *Journal of Monetary Economics* 48, pp. 465-512.

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

Edelstein, P. and L. Kilian (2009) "How sensitive are consumer expenditures to retail energy prices?" *Journal of Monetary Economics* 56:6, pp. 766-779.

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* (forthcoming).

Hendrickson, C, L.B. Lave and H.S. Matthews (2006), *Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach*, Resources for the Future Press.

HIS Global Insight, (2009) "Measuring the Economic and Energy Impacts of Proposals to Regulate Hydraulic Fracturing," 17 pages.

Jaramillo, P., Griffin, W.M. Griffin and H.S. Matthews (2007), "Comparative Life Cycle Air Emissions of Coal, Domestic Natural Gas, LNG, and SNG for Electricity Generation." *Environmental Science & Technology* 41 (17); 6290-6296.

Kleit, A.N., S. Blumsack, Z. Lei, L. Hutelmyer, M. Sahraei-Ardakani and S. Smith (2011), "Impacts of Electricity Restructuring in Rural Pennsylvania," report for the Center for Rural Pennsylvania, http://www.rural.palegislature.us/electricity_restruct2011.pdf.

Marcellus Shale Committee, (2009) "MSC Industry Progress Report Survey Results," May 18.

Miller, R.E. and P.D. Blair (1985) Input-output Analysis Foundations and Extensions, Cambridge University Press, 464 pages.

Pennsylvania Department of Labor and Industry (2010) "The Pennsylvania Green Jobs Report: Part I," January, 40 pages.

Snead, Mark C. (2002) "The Economic Impact of Oil and Gas production and Drilling on the Oklahoma Economy." Office of Business and Economic Research, College of Business Administration, Oklahoma State University, 22 pgs.

United States Geological Survey (2002) "Assessment of Undiscovered Oil and Gas Resources of the Appalachian Province," U.S. Department of Interior, Open-File Report 2008–1287.

Walker, D. and N. Sonora (2005) "The Economic Impacts of the Natural Gas Industry in La Plata County, 2003-2004." School of Business Administration, Fort Lewis College, Durango, CO. 18 pgs.

Yucel, M. (1986) "Dynamic analysis of severance taxation in a competitive exhaustible resource industry," *Resources and Energy* 8:3, pp. 201-218.

Yucel, M. (1989) "Severance taxes and market structure in an exhaustible resource industry," *Journal of Environmental Economics and Management* 16:2, pp. 134-148.

Appendix A: Survey Form

Confidential Survey: Pennsylvania Marcellus Shale Gas Activity

Company: ______________________

Contact Name: ______________________

Phone Number: ______________________

Email Address: ______________________

Note: All values should be for the Pennsylvania Marcellus on a calendar year basis

Data should pertain to wells operated by the company (Gross Operated Basis)

Cumulative as of year end 2010 (inception to date)

Total Spending 1,000$	
Wells drilled to total depth, #	
Vertical	
Horizontal	

		Actual		Planned	
	Units	2009	2010	2011	2012
Total Spending	1,000 $				
Lease & Bonus	1,000 $				
Exploration	1,000 $				
*Upstream: Drilling & Completion**	1,000 $				
*Midstream: Pipeline & Processing**	1,000 $				
Royalties	1,000 $				
Other	1,000 $				
Operated Gross Acres under Lease	#				

		2009 end	2010 end of quarter			
Rig & Well Count	Units	IV	I	II	III	IV
Rigs Operating	#					
Rigs used for vertical sections	#					
Rigs used for curve and lateral sections	#					
Rigs used for vertical, curve, and lateral sections	#					
Wells producing	#					

		2009 end	2010 total output			
Drilling & Production	Units	IV	I	II	III	IV
Wells Drilled to total Depth	#					
Vertical	#					
Horizontal	#					
Production that you operate						
Gross Dry Natural Gas	mcf					
Oil, Condensate, Natural Gas Liquids	barrels					

Appendix B: Econometric Model and Results

In this Appendix we develop an econometric model that identifies and measures the sensitivity of energy consumption to economic growth and energy prices. The model represents end-use energy demand in all sectors of the Pennsylvanian economy, including households, manufacturing, services, agriculture and electric power generation. The demand for primary fuels used in power generation — oil, natural gas and coal — is derived from the demand for end-use electricity consumption. End-use electricity prices are determined from average generation costs and transmission and distribution charges. The overall model provides a tool for policy makers to assess the impacts of economic growth, energy prices and electricity capacity choices on energy demand, prices and environmental emissions.

Developing a model of energy demand that provides stable forecasts and sensible policy analysis requires a combination of economic analysis, data measurement and quantitative modeling. Empirical models consistent with economic theory often ensure that policy and market shocks yield sensible results, such as consumption falling with increasing prices. Practical knowledge of the structure of energy consumption and the forces affecting its development is also critical to successful model development. The judgments made on the basis of these guidelines are discussed in this report.

Section B1 provides an overview of electricity consumption and generation trends in the Pennsylvanian economy. Section B2 presents the model, including the mathematical specification of the energy demand models for the residential, commercial and industrial sectors, and the formulation of the model for electric power generation and fuel use. In section B3 the econometric methods are employed to estimate how electricity users respond to prices and economic activity. We then put the forecasting model to work in section B4 given assumptions on future prices for the primary fuels and projections of population, inflation and economic growth to generate baseline projections for electricity demand, generation costs, electricity rates and carbon emissions.

B1. Pennsylvania's electricity market

The consumption of electricity in Pennsylvania has tended to grow significantly slower than the national average growth rate over the past few decades. Table B1 provides summary statistics of the growth in electricity use in the residential, commercial and industrial sectors of Pennsylvania. The industrial sector consists of manufacturing (NAICS 31-33); agriculture, forestry and fisheries (NAICS 11); mining, including oil and gas extraction (NAICS 21); natural gas transmission (NAICS 2212); and construction (NAICS 23). All other sectors are included in the commercial sector aggregate. Across all sectors, growth in electricity use was most rapid during the 1970s at 2.9% per annum. The growth rate for total U.S. electricity use was 4% over the same period. Subsequently, growth rates for power use in Pennsylvania fell to around 1.5% in the 1980s and 1990s, with growth in the industrial sector essentially flat. Over the last decade, total electricity use grew at just 1.1% per annum, although this was actually above the national average rate, which fell to just 0.6% due to the late-2000s economic decline.

Table B1: Average Annual Growth Rates for Electricity Use by Sector by Decade

Period	Residential	Commercial	Industrial	Total
1970-79	3.3%	5.0%	1.8%	2.9%
1980-89	1.9%	3.3%	0.1%	1.5%
1990-99	1.7%	3.6%	-0.1%	1.6%
2000-09	2.1%	1.0%	0.1%	1.1%

Source: U.S. Energy Information Administration

Figure B2 demonstrates that the industrial sector consumed more electricity than both the residential and commercial sector combined in 1970. However, with most of the growth in Pennsylvania electricity use occurring in the residential and commercial sectors, by 2010 both constituted a greater share of total electricity use than the industrial sector. The residential sector is now the single largest consuming sector requiring over 55 million megawatt hours in 2010. Commercial sector use is second with consumption of 47.5 million megawatt hours, and industrial use is narrowly third with 45.7 million megawatt hours. In total these sectors required more than 148 million megawatt hours of electricity in 2010.

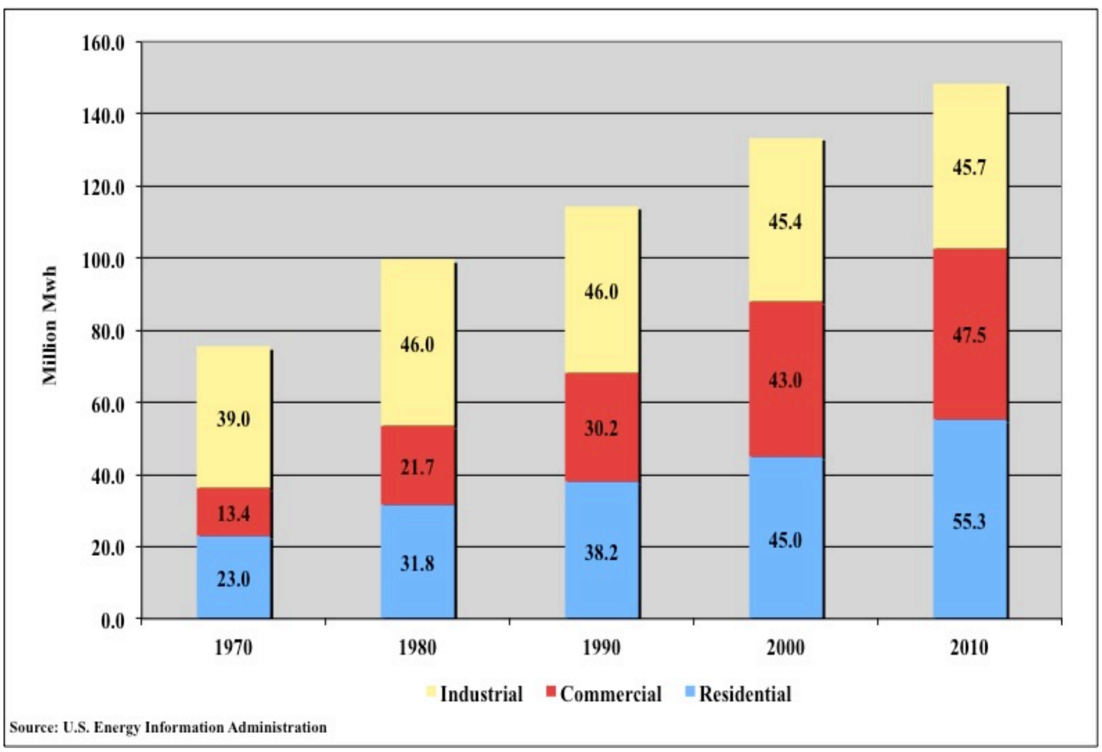

Figure B1: Electricity consumption by sector

Table B2: Population Levels (Millions) and Growth Rates in Pennsylvania

	Population at Start	Growth Rate
1970-79	11.8	0.0%
1980-89	11.9	0.0%
1990-99	11.9	0.3%
2000-09	12.3	0.3%
2010	12.6	

Although growth in electricity consumption has been sluggish in Pennsylvania, it has exceeded population growth. Table B2 shows the population to be stable in the 1970s and 1980s, before growing at an average rate of 0.3% during the 1990s and 2000s.

One factor that has allowed electricity use to generally rise faster than population growth is that real rates for electric power have not risen substantially over the sample period. In particular, electric rates for many customers were frozen as part of Pennsylvania's transition to deregulated electricity markets. Trends in real electricity rates by sector are displayed in Figure B2. During the 1970s, real rates for residential and commercial users rose 2.3% and 2.5% per annum respectively. Meanwhile, rates for industrial users increased nearly 7% per annum over the same period. However, real rates began to fall over the 1980s and 1990s, to the extent that by the early 2000s, they had even fallen below their 1970 mark in both the residential and commercial sectors. This was due to a combination of the mandated retail rate freeze alongside climbing fuels prices, particularly natural gas. More recently (2009 and 2010), rates have been heading upward again as Pennsylvania's utilities have emerged from the period of rate freezes and finalized the transition to competitive retail electricity markets. During this same time period, growth in the residential electricity sector was nearly 9%.

Much of the historical variation in end-use electricity rates is associated with changes in the average costs of generating electric power. Under traditional public utility pricing, rates are established on the basis of the average cost of production. These costs depend upon the unit operating costs of the various plants in the system and the mix of generation assets. Unit operating costs depend upon capacity utilization and the amount of energy in fuels required to generate a unit of electricity. Going forward, as Pennsylvania fully transitions to deregulated electricity markets, the electric generation component of monthly electricity bills for virtually all Pennsylvania customers will be reflective of conditions in the PJM wholesale electricity market rather than average production costs.[6] As natural gas prices are an important determinant of electricity prices in the PJM market, particularly during peak demand periods,

[6] PJM is the Regional Transmission Organization whose footprint covers almost all of Pennsylvania, along with all or parts of twelve other states and the District of Columbia. PJM operates the high-voltage transmission network within its footprint and runs competitive wholesale markets for electric energy and capacity. With deregulation, all electricity consumers in Pennsylvania are asked to choose a specific supplier for electric generation service;

monthly electricity bills for Pennsylvania customers will become increasingly reflective of Mid-Atlantic regional natural gas prices.

Coal is the largest source of electrical power generation in Pennsylvania. Figure B3 illustrates that since 1990 coal-fired generation has produced up to 123 million Mwh, which was the case in 2006 and 2007, although in recent years coal generation has fallen slightly. Pennsylvania is also the second-largest producer of nuclear power in the U.S., with five operating nuclear plants producing 35% of total in-state generation. Nuclear power generation has risen since 1990, when it generated around 60 million Mwh, to nearly 80 million Mwh in 2010. We note here that Pennsylvania is the largest exporter of electricity in the U.S., with around one-third of electricity produced in Pennsylvania sold to utilities and customers in other states. Pennsylvania also imports smaller amounts of power from other states, particularly from plants situated along the Ohio River Valley. Thus, in-state generation figures represent sales to Pennsylvania consumers as well as exports.

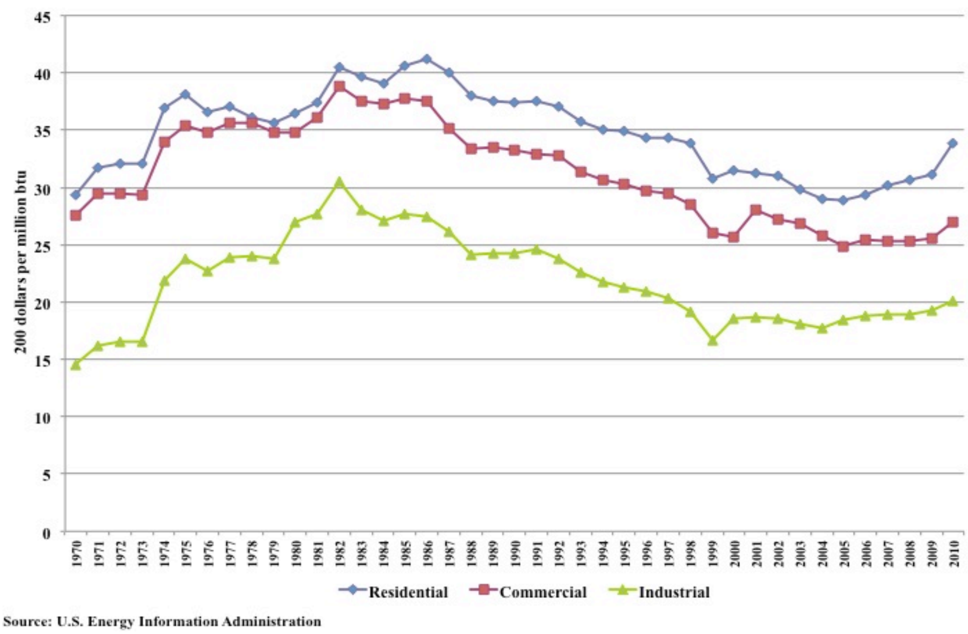

Figure B2: Real Electricity Rates by Sector

Natural gas and renewable energy traditionally constitute only negligible shares of Pennsylvania's electric generation capacity portfolio. However, production from natural gas plants has increased by an order of magnitude since 2000, from 3 million Mwh in 2000 to over 30 million Mwh in 2010. This rapid growth in the use of natural gas to generate electricity reflects a national trend. Even though the price for natural gas is substantially higher than coal on a thermal equivalency basis, natural gas plants are less capital intensive and do not involve

those who do not choose a specific supplier are assigned to a state-determined "default supplier." The generation price charged by the default supplier is reflective of wholesale market prices in PJM.

the extensive and elaborate pollution control systems that many coal-fired plants require. As a result, a substantial proportion of new electric generation capacity in Pennsylvania since the late 1990s has been natural gas-fired capacity (see Figure B4).

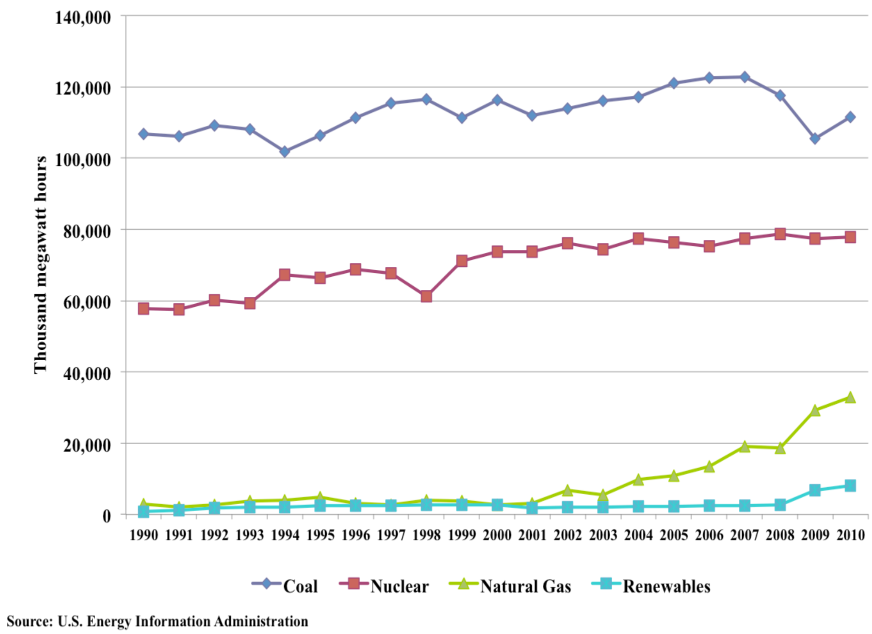

Figure B3: Electricity Generation by Type

The four primary sources of electricity (coal, nuclear, natural gas and renewables) now generate more than 230 million Mwh, which is 81 million Mwh greater than Pennsylvanian end-use. This surplus is mainly exported to other states throughout the East Coast and Mid-West.

In addition to the mix of capacity, another important cost determinant is the rate of capacity utilization. Figure B5 reports the capacity utilization rates for the different power generating technologies aside from renewables. Capacity utilization for nuclear power is consistently above 90% in Pennsylvania, while coal-fired power plants have generally been operating at around 70% capacity. In contrast, natural gas has traditionally operated at below 10% capacity, although over recent years its capacity utilization has steadily increased, to the point of reaching 35% in 2009. These variations in capacity utilization reflect the role various types of capacity have in meeting electricity loan balancing requirements. Natural gas and oil capacity, for example, are often used to meet peak loads while coal, nuclear and hydroelectric capacity services base load capacity that varies little hour-to-hour.

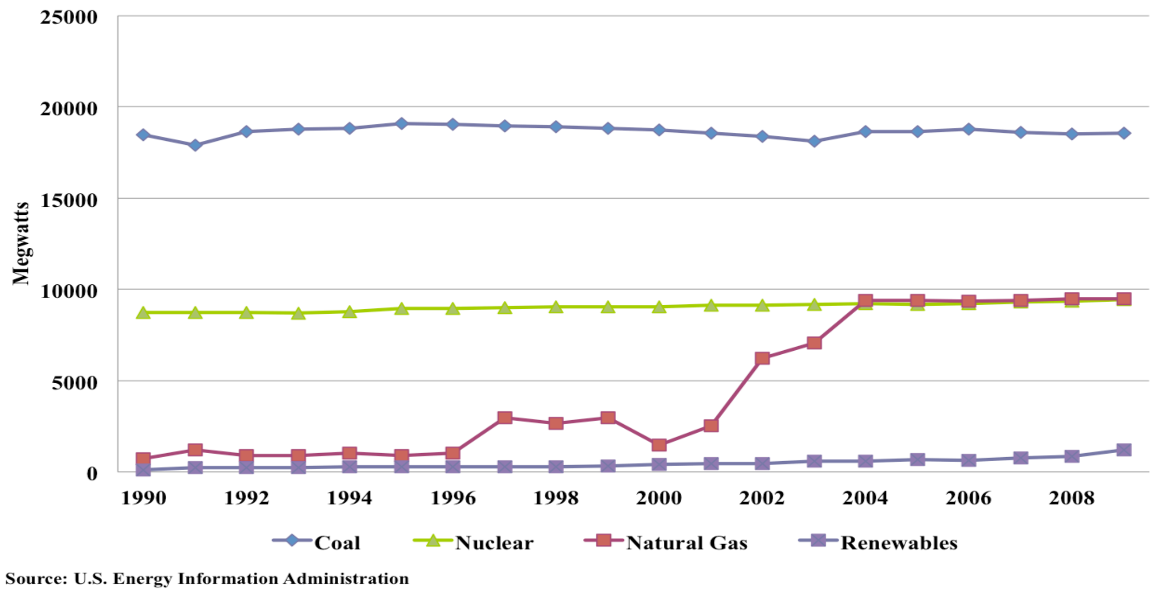

Figure B4: Electricity Generation Capacity in Pennsylvania

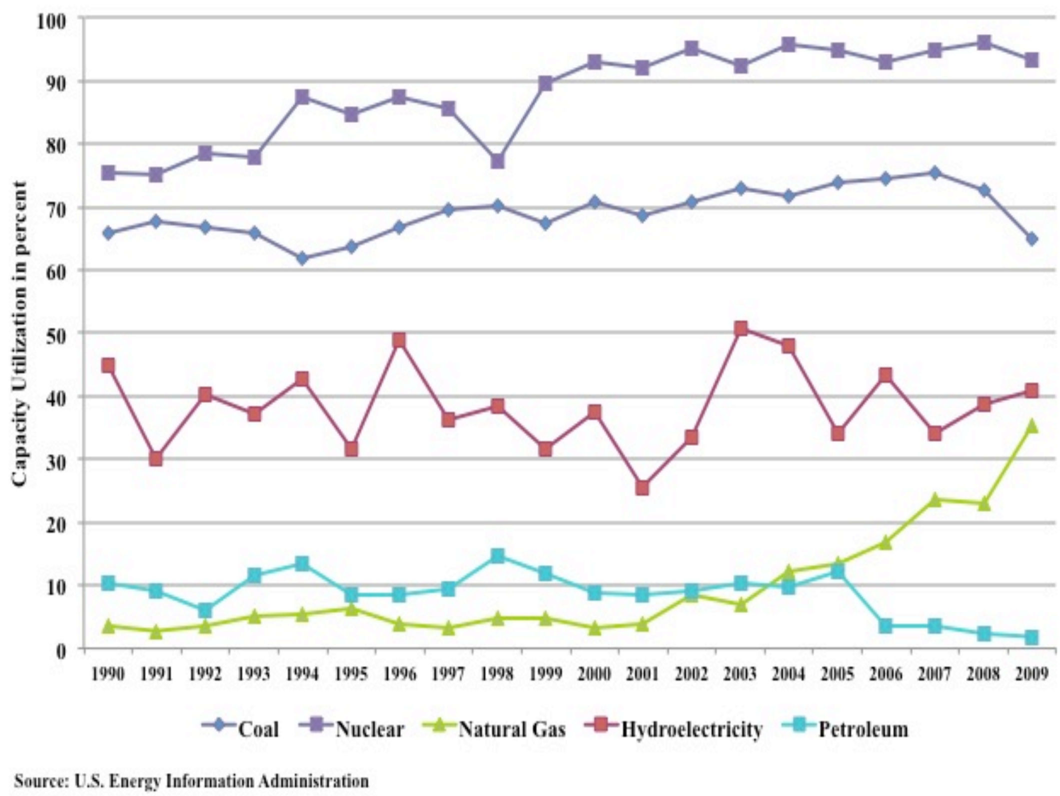

Figure B5: Electric Power Capacity Utilization Rates

B2. The Forecasting Model

The forecasting framework is built upon two modeling perspectives. First, the end-use aggregate demand for fuels in the residential, commercial and industrial sectors are modeled from an economic perspective in which energy demand is a function of relative prices, population and the level of economic activity. On the supply-side for electricity, however, an engineering-economic perspective is adopted in which capacity, utilization rates and heat rates are specified exogenously, with the exception of electricity generation from natural gas, which is determined as the difference between demand and other generation sources. Hence, natural gas is modeled as the swing fuel, which is consistent with the recent past in Pennsylvania. In most economic evaluations of alternative energy systems, such as solar, wind and biomass, natural gas prices are used as the basis for comparison. In other words, the opportunity cost of electricity from these new technologies is the avoided cost of electricity produced from natural gas.

The forecasting model determines electricity supply, demand and prices, given exogenous assumptions for primary fuel prices, economic growth, inflation and capacity expansion plans. A schematic of the line of causality between these assumptions and the endogenous variables is presented below in Figure 9 in the text above. End-use electricity demands and net electricity exports determine electric power generation requirements, which then drive the consumption of fuels in power generation. Generation capacity, operating rates and heat rates of operating units determine the composition of fuel consumption by electric utilities and the average cost of electricity generation. Retail electricity prices are calculated by adding transmission and distribution charges to average generation costs.

As Figure 9 illustrates above, carbon emissions are tracked for each sector of the economy. The carbon tracking provides a nearly complete accounting of carbon dioxide emissions in the Pennsylvanian economy (including electricity exports). Carbon emissions, therefore, are endogenous and depend upon energy prices and economic activity driving energy demand and the choice of electricity generation capacity. The feedback of final electricity demand on the demand for fuels and end-use electricity prices allows an integrated evaluation of electricity demand and fuel choice in power generation.

There are five main components of the model. The first three include systems of energy demand equations for the residential, commercial and industrial sectors. The fourth involves the demand for transportation fuels, including gasoline and diesel fuel. The fifth and final component involves the electricity generation sector. The following sub-sections describe the formulation of the models within each of these components.

The energy demand equations in the residential, commercial and industrial sectors are specified as expenditure systems. This approach incorporates two key features of demand systems consistent with consumer utility maximization or producer cost minimization. The first feature is that only relative prices matter in determining the mix of fuels. The importance of relative price changes follows from the homogeneity condition of demand equations, which implies that if all prices increase by the same proportionate amount then total energy expenditures also increase by the same percentage. The other important property involves symmetry. If the demand for fuel oil increases when relative propane prices increase, then propane and oil are substitutes. In this case, the demand for propane should increase with relatively higher oil prices. An energy demand forecasting system with inter-fuel substitution should have these symmetric price effects.

Economists have developed a variety of methodologies for ensuring consistency between demand equations. One group of methods uses flexible functional forms to approximate systems of demand equations derived from neoclassical cost or expenditure functions, such as the translog (TL) and generalized Leontief (GL). Considine (1989) shows that the nonlinear price elasticities associated with these forms often result in counter-intuitive results, such as positive own price elasticities. In addition, incorporating dynamic quantity adjustments is impossible using the TL and highly restrictive for the GL.

The linear logit (LL) model of cost shares developed by Considine and Mount (1984) provides an attractive alternative to conventional demand systems. Many researchers associate logit functions with discrete choice models. Logistic functions ensure that probabilities are non-negative and sum to one. These properties also must hold for cost shares. Considine and Mount (1984) derive the symmetry and homogeneity conditions for the linear logit cost share system. They also show that this specification is particularly well suited for modeling dynamic adjustments. A dynamic specification is essential because it is unlikely that energy consumers would respond fully to shocks within one period.[7] Furthermore, Chavas and Segerson (1986) argue that the logit approach does not place any restrictions on autoregressive processes of structural error terms.

There are several applications of linear logit demand models that examine various aspects of energy demand. Considine (1989) uses the model to examine how fuels should be grouped in substitution models and estimates the impacts of environmental regulations and policies on natural gas allocation. The report by Jones (1995) applies the model to U.S. industrial energy demand and finds that it out performs other models in terms of fitting observed data and in providing sensible demand elasticities. Considine (2000b) estimates linear logit demand models to estimate the sensitivity of energy demand to fluctuations in climate conditions. Considine and Rose (2000) use the model to forecast world natural gas, petroleum and coal consumption out to the year 2020 under alternative oil price scenarios and carbon tax policies.

This study adopts the following nested two–stage approach for the residential, commercial and industrial sectors. The first stage determines the level of total energy consumption. The second stage model disaggregates aggregate energy consumption by fuel type. The demand models involve a non-homothetic, two-stage optimization framework. The first tier assumes an aggregate energy demand relationship:

$$\ln Q_t^d = \eta_r + \kappa_r \ln\left(P_{rt}^d / PGDP_t\right) + \mu_r \ln X_t + \lambda_r \ln Q_{rt-1} + \varepsilon_{rt} \qquad (1)$$

[7] Even though the input-output analysis above is static, the linear logit model by allowing dynamic adjustments allows more accurate estimates of static as well as dynamic elasticities of demand.

where Q_{rt}^{d} is a divisia quantity index of total energy demand; P_{t}^{d} is a divisia index of aggregate fuel prices; X_t is an exogenous demand shifter that differs by sector; $\eta_r, \kappa_r, \mu_r, \lambda_r$ are unknown parameters; and ε_{rt} is a random error term. For the residential and commercial sectors, we account for the effect of a change in population on total energy demand by scaling Q_{rt}^{d} by the population of Pennsylvania. The divisia price index is a share weighted moving average of logarithmic first differences in fuel prices defined by the following identity:

$$P_t = P_{t-1}\left[1 + 0.5\sum_{j=1}^{n}\left(S_{jt} + S_{jt-1}\right)\left(\ln P_{jt} - \ln P_{jt-1}\right)\right], \qquad (2)$$

where *n* indexes the fuels used in the particular sector. For instance, prices for electricity, liquid propane gas and natural gas comprise the divisia price index for the residential sector. The corresponding divisia quantity index is defined as energy expenditures divided by the divisia price index.

This specification assumes that the fuels in the energy price index are weakly separable from other goods and services. In other words, the marginal rate of substitution between two fuels is independent of the rate at which aggregate energy substitutes with other goods. Substitution possibilities between energy and other goods and services are likely to be very limited within the time span considered in this study.

In the second stage, a system of share equations determines the mix of fuels within each sector's energy aggregate. The unrestricted linear logit model of cost shares is as follows:

$$S_{it} = \frac{P_{it}Q_{it}}{C_t} = \frac{e^{f_{it}}}{\sum_{j=1}^{n} e^{f_{jt}}} \;\forall\; i\text{, where} \qquad (3)$$

$$f_{it} = \alpha_i + \sum_{j=1}^{n}\beta_{ij}\ln\left(P_{jt}\right) + \gamma_i Q_t + \phi\ln\left(Q_{it-1}\right) + \varepsilon_{it}, \qquad (4)$$

where Q_{it} is the quantity of fuel *i* in period *t*; P_{it} is the price of fuel *i*; C_t is expenditure on fuels in the aggregate; $\alpha_i, \beta_{ij}, \gamma_i, \phi$ are unknown parameters to be estimated; and ε_{it} is a random disturbance term. The inclusion of Q_{it} in equation (4) allows for non-homothetic demand functions within a two-stage demand model similar to the formulation developed by Segerson and Mount (1985).

Substituting (4) into (3), taking logarithms, normalizing on the n^{th} cost share, and imposing symmetry and homogeneity following the procedures developed by Considine and Mount (1984), yields the following share system:

$$ln\left(\frac{S_{it}}{S_{nt}}\right) = (\alpha_i - \alpha_n) - \left[\sum_{k=1}^{i-1} S_k^* \beta_{ki}^* + \sum_{k=i+1}^{n} S_k^* \beta_{ik}^* + S_i^* \beta_{in}^*\right] ln\left(\frac{P_{it}}{P_{nt}}\right)$$
$$+ \sum_{k=1}^{i-1} (\beta_{ki}^* - \beta_{kn}^*) S_k^* ln\left(\frac{P_{kt}}{P_{nt}}\right) + \sum_{k=i+1}^{n-1} (\beta_{ik}^* - \beta_{kn}^*) S_k^* ln\left(\frac{P_{kt}}{P_{nt}}\right) + (\gamma_i - \gamma_n) lnQ_t$$
$$+ n_i \ln(HDD_t) + \varphi ln\left(\frac{Q_{it-1}}{Q_{nt-1}}\right) + (\varepsilon_{it} - \varepsilon_{nt}) \quad (5)$$

for all fuels, i, in the cost share model, where S_k^*'s are the mean cost shares. The residential and commercial energy cost share systems model the substitution between three fuels and therefore include two equations of this basic form. In contrast, the industrial energy cost share system is a four-fuel model and so consists of three equations. In equation (5) we have also added an exogenous variable measuring the total yearly heating degree days in Pennsylvania (HDD). The residential energy cost share system includes this variable in order to capture demand for energy needed to heat residential homes. (We also include HDD as one of the exogenous demand shifters in the estimation of equation (1) for the residential sector.) Notice that equations (1) and (5) contain lagged quantities, which allows dynamic adjustments in demand and the computation of short and long–run elasticities. The price and income (output) elasticities are share weighted functions of the parameters. The adjustment parameter, ϕ, determines the difference between short and long–run elasticities.

To forecast future energy consumption and carbon emissions, we establish a baseline projection of gasoline and diesel fuel consumption in the transportation sector. We estimate the working stock of vehicles in Pennsylvania and assume some set utilization rate in terms of miles traveled per year along with assumptions on fuel economy. Unlike the residential, commercial and industrial sectors, very limited or no interfuel substitution yet occurs in the transportation sector, which for this study includes gasoline and diesel fuel. The models in this sector take the same form as equation (1). In this case, the demand shifter includes real personal disposable income and price is the real price including taxes.

The model computes electricity generation by fuel type on the basis of available capacity and average operating rates. For instance, generation from capacity *i* in year *t* in megawatt hours is defined as follows:

$$G_{it} = H_i \times C_{it}, \quad (6)$$

where H_{it} is the number of hours capacity is operated and C_{it} is rated capacity in megawatts.

Fuel demand is simply generation multiplied by the average heat rate:

$$F_{it} = HR_i \times G_{it}, \quad (7)$$

where HR_i is the heat rate in tons of oil equivalent per megawatt hour. The forecasts produced below assume fixed operating hours and heat rates, computed using historical values.

A previous version of this study used a linear logit cost share system to model the derived demand for fuels in electric power production. The problem with this approach is that capacity constraints are not explicitly considered. Moreover, a demand system estimated during a period with coal, fuel oil and gas-oil would most likely not be applicable to one with a substantial share of natural gas. Although relative prices for these fuels do indeed provide estimates of how heat and utilization rates vary with relative fuel prices, the relative environmental costs and benefits of these fuels are not considered. If oil capacity is replaced by natural gas and coal capacity hours and capacity are fixed, then relative prices cannot affect gas generation because it is swing capacity, or the last units operated to meet system power load requirements. Introducing relative price effects, therefore, is a moot issue given these assumptions.

The computation of forecasted power generation and fuel use by electric utilities can be seen as a sequence of steps. First, total electricity production is determined by adding predicted electricity demand and power line losses. Generation from natural gas-fired capacity is determined by the difference between power demand and the sum of generation from other generation sources. Marginal generation costs for electricity are computed by taking an output-weighted average of generation costs by capacity, which is simply the product of fuel prices and heat rates. Margins for transmission and distribution costs are estimated over the historical period by subtracting marginal generation costs from end-use electricity prices, which reflect charges for stranded costs. Adding these margins to average generation costs projects end-use electricity prices. This formulation allows end-use electricity prices to vary with oil, coal and natural gas prices, which then feedback on electricity demand and production.

A list of the endogenous variables in the energy demand forecasting model appears in Table B3. Coal, petroleum, nuclear, hydroelectric, solar, other renewable sources, or natural gas-fired fossil fuel power generation can meet demand requirements. The cost share systems include an aggregate energy quantity equation. The quantities are derived by multiplying energy expenditures, which equal the divisia price index multiplied by the corresponding quantity index, by the respective cost share and then dividing by the appropriate price. The model is programmed using the econometric software package, Time Series Processor (TSP) 5.1 from Stanford University.

Table B3: Model endogenous variables and identities

Endogenous Variables	***Type***	***Endogenous Variables***	***Type***
Residential Sector		*Commercial Sector*	
Divisia energy price	I	Divisia energy price	I
Aggregate energy quantity	B	Aggregate energy quantity	B
Cost shares & quantities		Cost shares & quantities	
Natural Gas	B	Natural Gas	B
Liquid Propane Gas, etc.	B	Petroleum Products	B
Electricity	B	Electricity	B
Electricity Generation		*Industrial*	
Generation & Fuel Use		Divisia energy price	I
Natural Gas	I	Aggregate energy quantity	B
Nuclear	B	Cost shares & quantities	
Coal	B	Natural Gas	B
Hydroelectric	B	Coal	B
Other Renewables	B	Petroleum products	B
Electric power generation	I	Electricity	B
Electricity consumption	I		
Average Generation Costs	I	*Transportation*	
Retail Electricity prices	B	Gasoline in road travel	B
		Diesel in road travel	B
I = Identity, B= Behavioral			

B3. Estimation Results

The parameters of the four energy demand models – residential, commercial, industrial and transportation – are estimated with econometric techniques. The presence of total energy quantity on the right-hand side of the cost share equations requires an instrumental variable estimation to avoid simultaneous equation bias in the estimated coefficients. The Generalized Method of Moments (GMM) estimator is employed, which corrects for hetereoscedasticity and autoregressive moving average error components in the stochastic error terms. The strategy for selecting the instrumental variables is similar for each sector; using prices lagged one-period, quantities lagged two periods and lagged values of the exogenous variables in the total energy quantity models, such as the number of customers or real production. Other exogenous variables and a time trend may also be included as additional instruments.

The GMM estimates for the residential energy model, which contains three estimating equations, appear below in B4. The parameters reported in the top half of Table B4 correspond with those that appear in equation (5) above. The parameter estimates for the two log cost share ratio equations have no clear, direct interpretation. Nevertheless, eight of the ten parameters of the residential cost share system are significantly different from zero, with probability values indicating less than 1% chance that the estimated coefficients are zero. To achieve an understanding of their implications, the elasticities of demand are reported below in Table B5, which we will turn to shortly.

Table B4: Parameter Estimates and Summary Fit Statistics for Residential Sector

Parameters*	Coefficient	t-statistic	P-value
β_{12}	-0.812	-6.9	[.000]
β_{23}	-0.851	-17.3	[.000]
β_{13}	-0.991	-32.6	[.000]
ϕ	0.864	23.4	[.000]
γ_1	-0.289	-1.5	[.124]
η_1	0.731	7.5	[.000]
α_1	-6.454	-7.4	[.000]
γ_2	-0.600	-1.8	[.070]
η_2	0.755	4.9	[.000]
α_2	-6.833	-5.0	[.000]
Dependent variable: $\ln(Q_e/POP)$			
Constant	-3.351	-6.9	[.000]
$\ln(P_e$ / PGDP)	-0.113	-2.9	[.004]
ln(Real DPI/POP)	0.116	3.3	[.001]
$\ln(Q_{e,t-1}/POP)$	0.600	5.1	[.000]
ln(HDD)	0.334	6.9	[.000]

Dependent Variable	Correlation Coefficient	Durbin Watson
Natural Gas	0.999	2.101
Liquid Propane Gas	0.999	1.185
Electricity	1.000	2.031
Energy Consumption per capita	0.820	2.362

NOTE: 1 = Natural Gas, 2 = Liquid Propane Gas, 3 = Electricity
*See equations (1) and (5)

Reported in the center of Table B4 are the parameter estimates from equation (1) above. The double log partial adjustment formulation of the total energy demand equation implies that the coefficients on price and the other exogenous variables in the equation are short-run elasticities. For example, the short-run own price elasticity of total residential energy demand, which is the sum of electricity, natural gas and petroleum products, is -0.11. Also included in this equation is real per capita personal disposable income as an exogenous demand shifter. We find that a 1% increase in per capita disposable income leads to a 0.12% increase in total energy demand in the short-run. In addition, we include the total heating degree days in 1 year as a measure of heating fuel demand and find that a 1% increase leads to a 0.33% increase in total energy demand in the short-run.

The summary fit statistics reported in Table B4 result from computing the predicted cost shares and using the cost share identity to compute predicted quantities. A static method was used so that past predictions of lagged quantities are not used. Although a dynamic simulation, which involves using lagged endogenous quantities, is used below in the forecasts, a static method of fit assessment is preferred so that errors are not propagated. Using a static-fit method reveals that the residential model provides an excellent fit of the quantities as measured by the R-squared measures of fit in Table B4. Moreover, the Durbin-Watson statistics indicate that an auto-correlated pattern in the residuals does not pose a serious problem.

The own, cross-price and output elasticities for the residential sector appear in Table B5. In all cases, we find the own price elasticities to be negative as expected. Focusing on the gross elasticities, the own price elasticity of demand for electricity is -0.03, which is very price inelastic and consistent with findings in many other parts of the world. This elasticity is statistically significant at the 5% level. The own price elasticity for natural gas is similar but insignificant. However, the own-price elasticity for liquid propane gas while still inelastic is larger in absolute terms at -0.13 and is highly significant.

The gross elasticities assume that the level of total household energy demand is held constant. In reality, changing relative fuel prices affect the price of aggregate fuels to households that in turn affects the level of energy consumption. The second group of elasticities in Table B5, labeled net elasticities, account for these effects on total energy consumption. Notice that the net own price elasticities of demand are larger in absolute terms. This is logical, given the negative own price elasticity of demand for aggregate household energy demand. The real per capita disposable income elasticities, which measure how substitution possibilities vary with the level of income, are also substantially larger than the gross income elasticities and are all significant at the 1% level. The short-run net income elasticities for natural gas, liquid propane gas and electricity are 0.55, 0.36 and 0.72, respectively.

The long run elasticities are reported in the last panel of Table B5. These elasticities are a function of the net elasticities divided by one minus the respective adjustment parameters. As expected, the long-run own price and income elasticities are substantially larger than the gross and short-run net elasticities. For example, the long-run own price elasticity of demand for electricity is -0.33 with income elasticity of 2.23. Finally, the elasticities for heating degree days show that a greater demand for heating fuel tends to raise demand for natural gas and liquid propane gas, but tends to reduce the demand for electricity. For example, a 1% increase in yearly heating degree days reduces electricity demand by 1.77% in the long-run.

Table B5: Own, Cross-Price, and Customer Elasticities for Residential Sector

Quantities	Natural Gas Price	Liquid Propane Gas price	Electricity Price	Real DPI/POP	Heating Degree Days
		Gross Elasticities			
Natural gas	-0.043	0.038	0.004	-0.089	0.377
probability value	[.110]	[.109]	[.758]	[.451]	[.000]
Liquid Propane Gas	0.052	-0.130	0.078	-0.399	0.401
probability value	[.109]	[.000]	[.002]	[.100]	[.000]
Electricity	0.003	0.030	-0.033	0.201	-0.354
probability value	[.758]	[.002]	[.014]	[.052]	[.000]
Quantities		***Net Elasticities***			
Natural gas	-0.074	0.007	-0.026	0.547	0.710
probability value	[.008]	[.797]	[.199]	[.000]	[.000]
Liquid Propane Gas	0.029	-0.152	0.055	0.361	0.735
probability value	[.383]	[.000]	[.012]	[.030]	[.000]
Electricity	-0.056	-0.029	-0.092	0.720	-0.021
probability value	[.015]	[.080]	[.001]	[.000]	[.633]
Quantities		***Net Long-Run Elasticities***			
Natural gas	-0.361	0.232	-0.011	0.316	3.600
probability value	[.082]	[.290]	[.922]	[.664]	[.000]
Liquid Propane Gas	0.347	-0.986	0.536	-1.738	3.779
probability value	[.245]	[.007]	[.005]	[.271]	[.000]
Electricity	-0.069	0.132	-0.328	2.229	-1.770
probability value	[.307]	[.036]	[.000]	[.002]	[.002]

The objective function value of the GMM estimator is distributed as a Chi-Squared statistic, providing a test of the over-identifying restrictions for the model. For the residential model the probability value for the over-identifying restrictions is 0.207, suggesting that the restrictions cannot be rejected. Hence, the overall model appears to be supported by the data sample.

The curvature conditions, which follow from consumer utility maximization, are checked at the mean of the data by computing the Eigenvalues of the first derivatives of the estimated demand functions. For consistency with economic theory, the implicit expenditure function should be concave, which occurs when the Eigenvalues are less than zero. The residential estimates imply that these conditions are satisfied. Hence the residential energy demand functions are properly signed and on this basis provide intuitively plausible results in policy simulations. In summary, the fit of the household sector model is excellent, the elasticities of demand seem quite reasonable and the diagnostic statistics support the specification.

We now turn to the commercial sector. The overall findings from the econometric estimation of the commercial energy demand model are quite similar to the residential result. As Table B6 indicates, three out of the eight parameters in the commercial cost share system are significant

Table B6: Parameter Estimates and Summary Fit Statistics for Commercial Sector

Parameters*	Coefficient	t-statistic	P-value
β_{12}	-0.445	-1.5	[.143]
β_{23}	-1.047	-14.7	[.000]
β_{13}	-0.967	-16.5	[.000]
ϕ	0.968	8.7	[.000]
γ_1	0.066	0.5	[.651]
α_1	0.009	0.1	[.959]
γ_2	-0.141	-0.6	[.564]
α_2	-0.210	-0.6	[.569]
Dependent variable: $\ln(Q_e/POP)$			
Constant	-0.727	-0.9	[.368]
$\ln(P_e$ / PGDP)	-0.044	-1.3	[.182]
ln(Commercial Production)	0.052	0.9	[.378]
$\ln(Q_{e,t-1}/POP)$	0.896	10.9	[.000]

Dependent Variable	Correlation Coefficient	Durbin Watson
Natural Gas	0.999	2.303
Petroleum Products	0.999	2.065
Electricity	1.000	2.647
Energy Consumption per capita	0.979	2.457

NOTE: 1 = Natural Gas, 2 = Petroleum Products, 3 = Electricity
*See equations (1) and (5)

at the 5% level. In addition, the coefficient on the lagged quantity index of energy demand is significantly different from zero in the aggregate commercial energy demand equation. The short-run aggregate price elasticity of demand for energy in the commercial sector is -0.04, although it is insignificant. The overall fit of the commercial sector is very strong, while the Durbin-Watson statistics do not suggest the presence of serial correlation in the error terms.

Economic activity in the commercial sector is used to shift the overall level of aggregate commercial energy use. We devise the measure of commercial production by adding the gross state product of the commercial sectors of Pennsylvania. The resulting elasticity of aggregate energy demand to commercial sector production is 0.05, although this is again insignificant. The elasticities for the commercial sector are reported in Table B7. We find most of these elasticities to be insignificantly different from zero. On the other-hand, Table B7 shows that all own-price elasticities are negative and therefore plausible. In addition, the curvature conditions are satisfied (implying that the demand equations are consistent with producer cost minimization) and the test of the over-identifying restrictions for the commercial model cannot be rejected. Overall, we again find that the econometric results yield sensible estimates for the elasticities and that the model would likely perform well in policy simulations.

Table B7: Own, Cross-Price, and Customer Elasticities for Commercial Sector

	Gross Elasticities			
Quantities	Natural Gas Price	Petroleum Product Prices	Electricity Price	Commercial Production
Natural gas	-0.081	0.059	0.022	0.066
probability value	[.215]	[.068]	[.575]	[.506]
Petroleum Products	0.124	-0.092	-0.031	-0.141
probability value	[.068]	[.029]	[.510]	[.483]
Electricity	0.007	-0.005	-0.002	0.000
probability value	[.575]	[.510]	[.822]	[.995]
Quantities	***Net Elasticities***			
Natural gas	-0.091	0.050	0.012	0.055
probability value	[.186]	[.116]	[.735]	[.380]
Petroleum Products	0.119	-0.097	-0.036	0.045
probability value	[.076]	[.024]	[.456]	[.403]
Electricity	-0.022	-0.034	-0.032	0.052
probability value	[.262]	[.159]	[.265]	[.375]
Quantities	***Net Long-Run Elasticities***			
Natural gas	-2.594	1.731	0.585	1.509
probability value	[.772]	[.793]	[.813]	[.751]
Petroleum Products	3.757	-2.880	-1.011	-1.649
probability value	[.785]	[.764]	[.813]	[.742]
Electricity	-0.055	-0.434	-0.351	0.501
probability value	[.950]	[.571]	[.552]	[.520]

Finally, we turn to the industrial model, with the econometric results displayed in Tables B8 and B9. Unlike the residential and commercial sectors, we model the substitution between four fuels (natural gas, petroleum products, electricity and coal) for the industrial sector. Hence the industrial cost share system consists of three equations of the form of equation (5) above. We include a measure of industrial production, defined as the total gross state product of the industrial sectors in Pennsylvania, as the exogenous demand shifter. The estimation results imply a short-run output elasticity of 0.02 for electricity in the industrial sector, which is insignificant.

Table B8: Parameter Estimates and Summary Fit Statistics for Industrial Sector

Parameters*	Coefficient	t-statistic	P-value
β_{12}	0.039	0.0	[.971]
β_{24}	0.631	0.4	[.707]
β_{13}	-0.726	-10.6	[.000]
β_{34}	-0.692	-4.3	[.000]
β_{14}	-2.174	-7.8	[.000]
β_{23}	-1.699	-4.2	[.000]
ϕ	0.760	5.3	[.000]
γ_1	-0.079	-0.2	[.834]
α_1	1.573	0.3	[.792]
γ_2	0.187	0.2	[.812]
α_2	-2.669	-0.2	[.830]
γ_3	-0.481	-1.4	[.152]
α_3	8.009	1.5	[.133]
Dependent variable: $\ln(Q_e/POP)$			
Constant	0.120	0.1	[.938]
$\ln(P_e$ / PGDP)	-0.075	-2.1	[.038]
ln(Industrial Production)	0.024	0.3	[.794]
$\ln(Q_{e,t-1}/POP)$	0.974	22.6	[.000]

Dependent Variable	Correlation Coefficient	Durbin Watson
Natural Gas	0.902	1.781
Petroleum Products	0.959	2.103
Electricity	0.635	2.220
Coal	0.954	2.050
Total Energy Consumption	0.899	2.188

NOTE: 1 = Natural Gas, 2 = Petroleum Products, 3 = Electricity, 4 = Coal
*See equations (1) and (5)

For the industrial sector model, the tests of the over-identifying restrictions are not rejected. Referring to Table B9, we again find that all the own-price elasticities are positive. Like the residential and commercial sectors, the short-run demand for electricity is extremely price inelastic with a short-run own price elasticity of -0.03. On the other-hand, this elasticity increases to -1.55 in the long-run, which is price elastic (although it is not estimated with sufficient precision to be significant).

The final block of estimated econometric equations includes the demands for gasoline and diesel fuel used in transportation. The results of this estimation appear in Table B10. The short and long-run price and income elasticities of demand are well within the range reported in the literature. Like electricity, the short-run demand for these fuels is very inelastic indicating that consumer expenditures do not fall sharply as prices increase.

Table B9: Own, Cross-Price, and Customer Elasticities for Industrial Sector

Quantities	Natural Gas Price	Petroleum Product Prices	Electricity Price	Coal Price	Industrial Production
		Gross Elasticities			
Natural gas	-0.057	0.124	0.136	-0.202	0.153
probability value	[.621]	[.337]	[.000]	[.000]	[.139]
Petroleum Products	0.223	-0.158	-0.345	0.281	0.419
probability value	[.337]	[.658]	[.084]	[.332]	[.480]
Electricity	0.059	-0.083	-0.028	0.053	-0.249
probability value	[.000]	[.084]	[.256]	[.057]	[.030]
Coal	-0.252	0.195	0.152	-0.095	0.232
probability value	[.000]	[.332]	[.057]	[.684]	[.447]
Quantities		***Net Elasticities***			
Natural gas	-0.073	0.108	0.119	-0.218	0.028
probability value	[.540]	[.394]	[.000]	[.000]	[.792]
Petroleum Products	0.214	-0.167	-0.354	0.272	0.035
probability value	[.354]	[.641]	[.079]	[.346]	[.786]
Electricity	0.022	-0.121	-0.066	0.016	0.018
probability value	[.266]	[.040]	[.018]	[.524]	[.796]
Coal	-0.265	0.182	0.139	-0.108	0.030
probability value	[.000]	[.362]	[.072]	[.646]	[.802]
Quantities		***Net Long-Run Elasticities***			
Natural gas	-0.857	-0.103	-0.055	-1.462	1.536
probability value	[.440]	[.932]	[.954]	[.196]	[.837]
Petroleum Products	0.583	-0.055	-1.784	0.826	2.578
probability value	[.679]	[.931]	[.241]	[.642]	[.834]
Electricity	-1.183	-1.775	-1.546	-1.206	-0.033
probability value	[.588]	[.432]	[.486]	[.580]	[.926]
Coal	-1.546	0.313	0.137	-0.895	1.846
probability value	[.149]	[.817]	[.877]	[.550]	[.852]

Table B10: Parameter Estimates & Elasticities Gasoline and Diesel Fuel Demand

	Coefficient	t-statistic	P-value
Dependent variable: $\ln(Q_{gasoline})$			
Constant	1.359	1.4	[.152]
$\ln(P_{gasoline} / PGDP)$	-0.061	-3.1	[.002]
ln(Real Personal Income)	0.017	0.9	[.363]
$\ln(Q_{gasoline,t-1})$	0.885	10.7	[.000]
Dependent variable: $\ln(Q_{diesel})$			
Constant	-3.518	-2.4	[.018]
$\ln(P_{diesel} / PGDP)$	-0.049	-1.3	[.210]
ln(Real Personal Income)	0.388	2.7	[.007]
$\ln(Q_{diesel,t-1})$	0.672	5.4	[.000]

Dependent Variable	Correlation Coefficient	Durbin Watson
Gasoline	0.823	1.234
Diesel	0.962	1.673

	Short-Run		
	Price Changes		
	Gasoline	*Diesel*	*Income*
Gasoline	-0.061 -3.1 [.002]		0.017 0.9 [.363]
Diesel		-0.049 -1.3 [.210]	0.388 2.7 [.007]
	Long-Run		
Gasoline	-0.530 -1.1 [.259]		0.149 1.0 [.299]
Diesel		-0.151 -1.0 [.318]	1.185 8.0 [.000]

B4. Baseline forecast

To perform forecasts with the econometric model, assumptions are required for economic growth, inflation and primary fuel prices. In addition, costs for new capacity additions are required. The full econometric model, including the behavioral equations discussed above, the cost, generation and retail rate equations for the electric power sector, and the carbon accounting relations, involves the simultaneous solution of 113 equations. Simulations are performed using TSP 5.1 Gauss-Newton algorithm. All simulations are performed from 2010 to 2020.

This study assumes that Pennsylvania's real gross state product grows at the national rates forecasted by the Energy Information Administration (EIA). This implies an average per annum growth rate for real gross state product of 2.8% over the simulation period. The price deflator and real disposable income are assumed to grow at 2.5% per annum (which is also similar to the growth rate projected by the EIA). Finally, we assume the population of Pennsylvania continues from the 2010 U.S. census figure of 12.7 million at the rate implied by U.S. Census population projections for Pennsylvania (an average of 0.2% over the simulation period). Hence by 2020 the population is projected to reach 12.9 million.

There is a high degree of uncertainty surrounding future trajectories of primary fuel prices. The EIA's latest set of projections calls for real oil price increases of less than 2% per annum. However, the International Energy Agency anticipates faster growth in real oil prices, with world oil production capacity struggling to keep pace with demand growth. This study assumes that recent tightness in primary fuel prices will continue into the future. Specifically, from 2010 averages of $79 per barrel for oil, $7.04 per thousand cubic feet for natural gas and $47 per ton for coal, real growth rates for oil, natural gas and coal, are 4%, 3% and 1% on average over the sample period, respectively. The natural gas price is a key variable in this study because it determines the marginal value of electricity generation costs, given that the model assumes by construction that natural gas is the swing fuel.

We consider a baseline scenario in which all new electricity generating capacity is natural gas. Given the above assumptions and assuming exports of electricity from Pennsylvania remain at current levels, total electric power consumption (residential, commercial and industrial) in the state increases from approximately 151 million Mwh in 2010 to 164 million Mwh by 2020. This is illustrated by Figure B6. Hence, by the end of the forecast period the state will require an additional 14 million Mwh of electricity. The average annual growth in consumption is nearly 1%.

Real generation costs are essentially flat, increasing marginally from $42 / Mwh in 2010 to $43 / Mwh in 2020. This is mainly because the average costs of the new natural gas capacity are predicted to fall in real terms. Hence lower real average generation costs largely offset the increase in real natural gas prices, which are assumed in the baseline forecast scenario. Figure B7 shows that these stable costs in turn lead to flat retail prices (after the fall in energy prices following the late 2000s recession). However, due to increasing consumption, real monthly household expenditures on energy rise over the forecast period. In particular, expenditures increase from $286 per month in 2010 to $323 per month by 2020 (see Figure B8). Moreover, flat real electricity prices lead to no great energy conservation efforts. For example, residential electricity consumption per customer, which was increasing until the recession in the late 2000s, is forecasted to continue steadily rising over the forecast horizon (see Figure B9).

Figure B10 shows that total carbon dioxide emissions increase from 2010 levels of roughly 233 million tons to a peak of nearly 238 million tons in 2016. At this point, carbon emissions start to decline, and reach approximately 236 million tons by 2020. Overall, the average annual increase in carbon emissions over the projection period is 0.1%. Note that these emissions result from the combustion of natural gas, coal and petroleum products in the residential, commercial, industrial and transportation sectors of the Pennsylvania economy. Carbon emissions start to fall from 2016 because all new generation capacity is natural gas, which is less carbon intensive than coal and petroleum products.

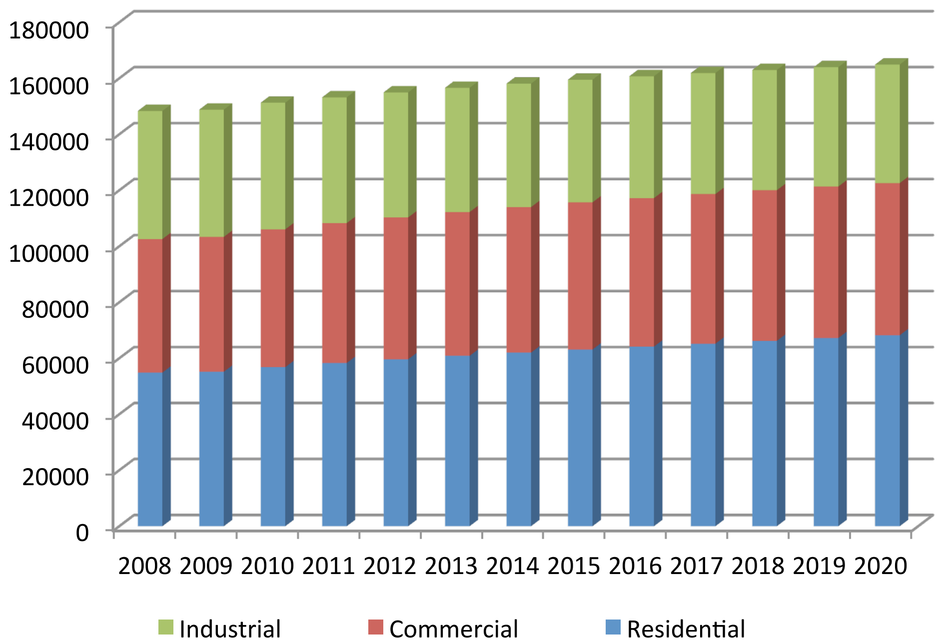

Figure B6: Forecast of Electricity Use in Pennsylvania (Thousand Megawatt hours)

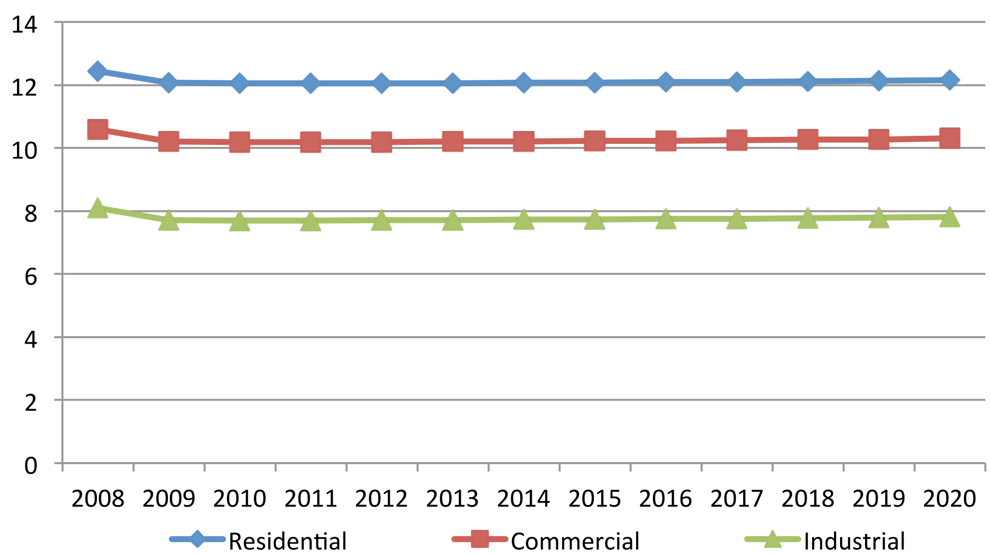

Figure B7: Real Electricity Rates by Sector (2011 cents/ Kilowatt hours)

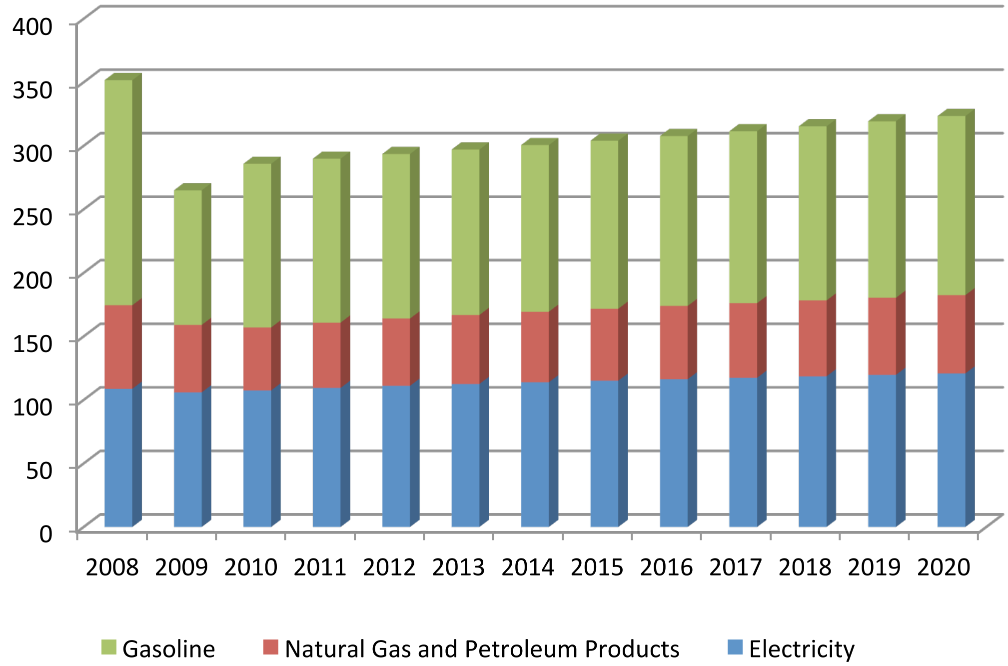

Figure B8: Real Monthly Household Energy Expenditures (2011 $ / month)

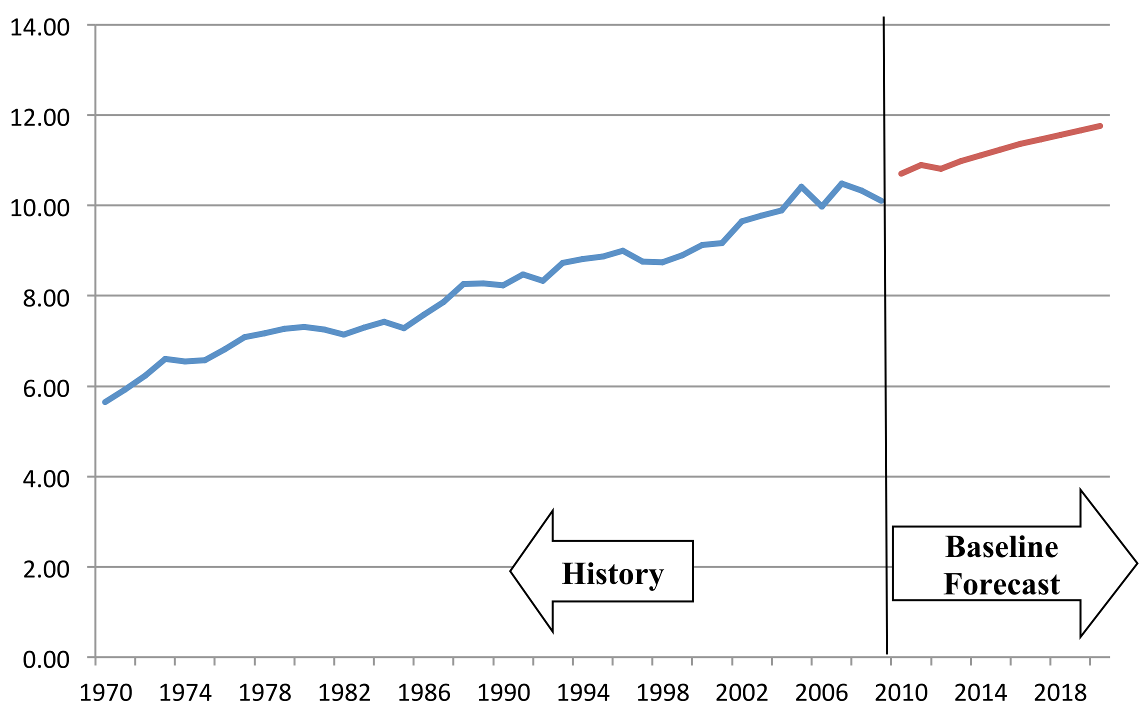

Figure B9: Electricity Use per Residential Customer (Megawatt hours / customer)

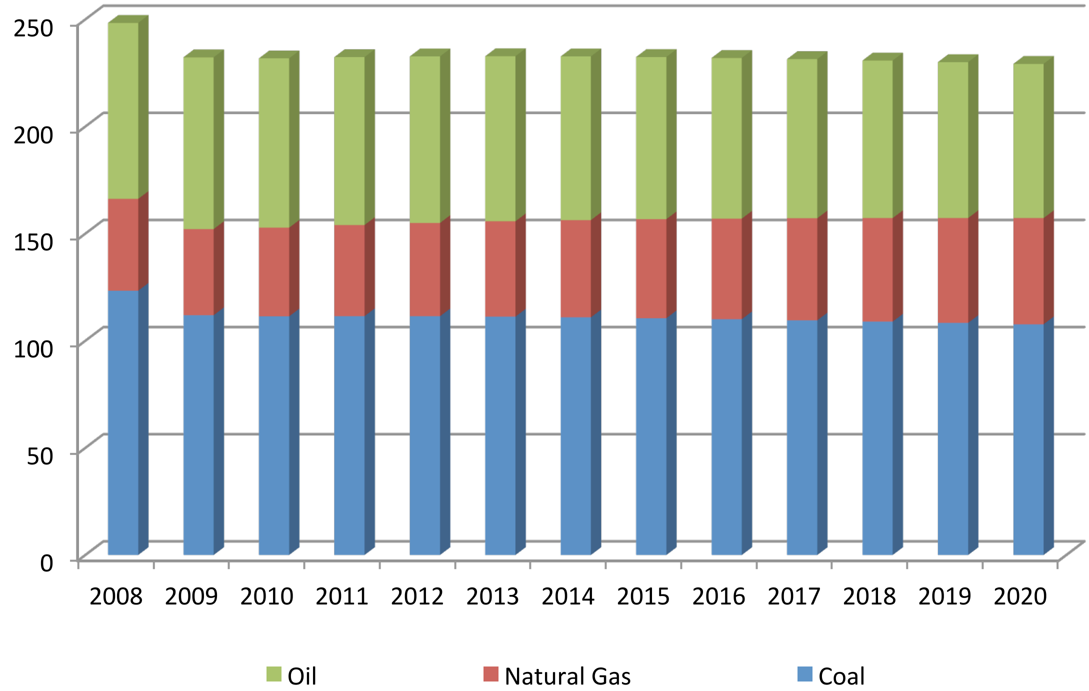

Figure B10: Carbon Dioxide Emissions in Pennsylvania (Million Tons)

B5. References

Chavas, J.P., and Segerson, K. (1986) "Singularity and Autoregressive Disturbances in Linear Logit Models," *Journal of Business and Economic Statistics* 4, 161-169.

Considine, T. J., and T. D. Mount, (1984) "The use of linear logit models for dynamic input demand systems," *The Review of Economics and Statistics* 64, 434-443.

Considine, T. J, and Rose, (2001) "The future role of natural gas in the world energy market: An overview," in The future role of natural gas in the world energy market, Markaz, ed. 9-23.

Considine, T. J., (1989) "Separability, functional form, and regulatory policy in models of interfuel substitution," *Energy Economics* 11, 82-94.

Considine, T. J., (2000) "Curvature restrictions in logistic cost share models," Department of Energy, Environmental, and Mineral Economics, The Pennsylvania State University.

Considine, T. J., (2000b) "Climate fluctuations and energy demand," *Resource and Energy Economics*, 22, 4, 295-312.

Jones, C., (1995) "A dynamic analysis of interfuel substitution in U.S. industrial energy demand," *Journal of Business and Economic Statistics* 13, 459-465.

Segerson, Kathleen, and Timothy D. Mount, (1985) "A Non-Homothetic Two-Stage Decision Model Using AIDS," *Review of Economics and Statistics* 67, 630-639.