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The Economic Benefits of Exelon Nuclear's Limerick Generating Station

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A report prepared by Jonathan A. Lesser, PhD
Continental Economics, Inc.

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6 Real Place, Sandia Park, NM 87047 • Main: 505.286.8833 • DC Office: 202.446.2062
www.continentalecon.com

Executive Summary[1]

Limerick Nuclear Generating Station (Limerick) provides 2,345 MW of around-the-clock, emissions-free, reliable energy - enough to power over two million homes. On average, the plant supplies about 10% of Pennsylvania's total electricity needs. In addition to the plant's electric reliability and environmental benefits, Limerick provides direct and indirect economic benefits to its host community and Pennsylvania as a whole.

This report analyzes the economic, system reliability and environmental benefits of Limerick. These benefits include:

- **Limerick reduced wholesale energy costs in Pennsylvania by $880 million in 2010.** Limerick provides economic benefits to Pennsylvania and to the surrounding Mid-Atlantic region by lowering wholesale market prices for electricity. Despite relatively low natural gas prices, which continued the trend of low wholesale electricity prices, Continental Economics estimates that Limerick's generation reduced total electricity expenditures by over $880 million in Pennsylvania and over $2.1 billion in PJM East.

- **Limerick is a major contributor to the Pennsylvania economy providing over $200 million in direct and indirect economic contributions annually in addition to reduced electricity prices.** Limerick has 826 full-time employees and also employs more than one thousand skilled, temporary contract employees during annual refueling outages. In addition to the direct benefits the plant provides in terms of lower electricity prices and greater electric system reliability, which flow through to the entire Pennsylvania economy, a number of economic impacts accrue from expenditures made by Exelon Nuclear to operate and maintain the plant. These impacts flow from employee compensation, in-state expenditures on goods and services needed to operate the plant, and local and state property tax payments. Limerick's direct economic contributions to the state of Pennsylvania are about $113 million annually, including about $75 million in wages and salaries, $2.9 million in property tax payments, and $35 million in purchases of goods and services from other Pennsylvania businesses. These local purchases and wage and salary payments indirectly support an additional 600 jobs and $115 million of output in the state economy. Moreover, by lowering the cost of electricity paid by Pennsylvania ratepayers by about $880 million annually, Limerick indirectly

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[1] This report was sponsored by Exelon Generation, a wholly owned subsidiary of Exelon Corporation. Exelon Nuclear, a business unit of Exelon Generation, operates Limerick Generating Station.

contributes over 10,500 jobs to the Pennsylvania economy because the lower electricity cost for businesses and individuals means they have more money available to spend on other goods and services.

- **Limerick enhances the environment by providing emissions-free,[2] around-the-clock power equivalent to removing almost 2.5 million cars from the road.** Limerick provides significant additional benefits by reducing the need to generate electricity from fossil fuels, thus reducing greenhouse gas emissions that cause global warming. If Limerick were retired from service, the electricity it currently provides could not be replaced by existing nuclear plants, which are free of carbon emissions. As a result, replacing the energy produced by Limerick would require increased natural gas-fired or coal-fired generation, producing large quantities of carbon dioxide (CO2), nitrogen oxides (NOx) and sulfur dioxide (SO2). We estimate that, without Limerick, CO2 emissions in 2010 would have increased by 13.2 million tons, equivalent to the emissions of over 2.5 million cars. We estimate the electricity generated by Limerick reduced emissions of SO2 by over 43,000 tons in 2010 and reduced emissions of NOx by over 16,000 tons.[3]

- **Limerick provides important reliability benefits for Southeastern Pennsylvania and the Philadelphia Area.** Limerick provides critical support for regional electric reliability, helping maintain uninterrupted electric service and preventing transmission network overloads.

Table EX-1 summarizes all of these impacts.

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[2] Unlike fossil-fuel generation, Limerick emits neither "criteria" pollutants regulated under the U.S. Clean Air Act or greenhouse gases, including carbon dioxide.

[3] According to data published by the U.S. Energy Information Administration, fossil-fuel generating plants in Pennsylvania emitted 780,000 tons of SO2 and 181,000 tons of NOx in 2008. By comparison, the current standard for light-duty cars and trucks is about 0.07 tons over the first ten years or 100,000 miles.

Table EX-1: Summary of Economic and Environmental Impacts of Limerick

Direct Benefits of Lower Electricity Wholesale Energy Market Prices in 2010	
Pennsylvania (Millions of $)	$880
Direct Employment Impacts	
Limerick full-time employees	826
Limerick payroll (Millions of $)	$75
Limerick Goods and Services Purchased in PA (Millions of $)	$35
Economic Multiplier Impacts	
Pennsylvania additional employment created by Limerick purchases of goods and services from in-state firms	~600
Pennsylvania additional employment created by lower electricity costs	~10,500
Environmental Impacts	
Avoided CO2 emissions in 2010 (Millions of tons)	13.2
Avoided CO2 emissions – equivalent number of cars (Millions)	2.5
Avoided SO2 emissions (Thousands of tons)	43.1
Avoided NOx emissions (Thousands of tons)	16.3

The Economic Benefits of the Limerick Nuclear Generating Station

1. INTRODUCTION

Located in Southeastern Pennsylvania, about 20 miles north of Philadelphia along the Schuylkill River, Limerick consists of two units, generating a total of 2,345 megawatts (MW). Unit 1 began commercial operation in February 1986, while Unit 2 began commercial operation in January 1990. Limerick produces highly valuable, low cost, greenhouse gas-free electricity to Pennsylvania and the surrounding region. In fact, nuclear power is the only greenhouse-gas free source of baseload (round-the-clock) generation. In 2010, the plant generated almost 19 million megawatt-hours (MWh) of electricity, almost 10% of Pennsylvania's total electricity needs. The electricity produced each year by Limerick is enough to power over two million Pennsylvania homes.[4]

Like all other markets for products and commodities, the power markets are based upon simple supply and demand principles. If supply is removed in the face of constant or growing demand, and constant or rising fuel costs, then prices will go up. In Pennsylvania, nuclear energy is the least expensive means of producing baseload electricity, therefore the supply needed to replace Limerick's output would have to come from other more expensive generation, inevitably leading to higher wholesale and retail electricity prices for consumers and businesses alike, with the resulting adverse impacts on the Pennsylvania economy.

Exelon Nuclear, the business unit of Exelon Generation which operates Limerick, requested Continental Economics, Inc. to prepare an analysis of the economic and environmental benefits provided by the facility. These benefits arise from several sources:

- Limerick’s around-the-clock output helps lower the cost of electricity in Pennsylvania, by $880 million each year.
- Limerick employs about 826 full-time staff, with an annual payroll of $75 million.
- The lower electricity costs for businesses and individuals in Pennsylvania means they have more money available to save, invest, and use to purchase other goods

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[4] Value is based on U.S. Energy Information Administration estimate of average annual residential electricity use in Pennsylvania of 10,106 kWh.

and services. Those lower electricity costs help Pennsylvania businesses stay more competitive and create thousands of jobs for Pennsylvania residents.

- Limerick's emissions-free generation reduces the need for fossil-fuel generating plants in PJM, thus reducing emissions of greenhouse gases, as well as sulfur dioxide and oxides of nitrogen.

1.1 Organization of the report

Section 2 of this report provides a review of the electric system reliability benefits Limerick provides. Section 3 identifies the significant electricity price savings to Pennsylvania consumers and businesses in 2010 as a result of Limerick. Section 4 examines the additional direct and indirect economic benefits provided by Limerick. Section 5 reviews Limerick's environmental benefits.

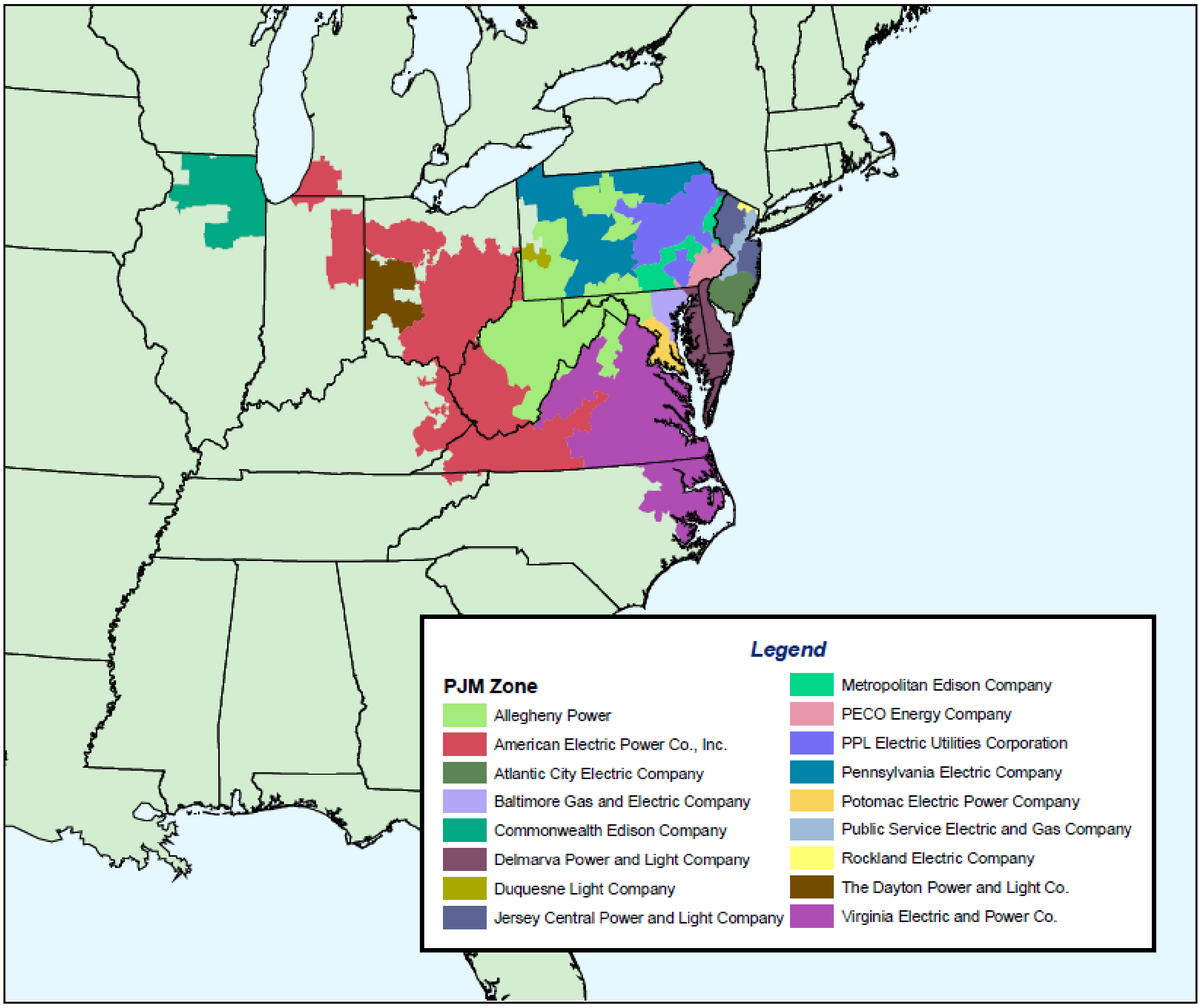
2. ELECTRIC RELIABILITY BENEFITS PROVIDED BY LIMERICK

Limerick is crucial to Pennsylvania and its consumers because of existing transmission constraints that limit the ability to import electricity into the state. Limerick helps ensure the "lights stay on" by providing needed capacity to meet peak demands, such as on hot summer days, and by providing what is called "regulation" or "load-following" services needed to adapt to instantaneous changes in total electric demand.

2.1 PJM and its sub-regions

PJM is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity across all or parts of the 13 states and the District of Columbia in its territory (See Figure 2-1). Acting as a neutral, independent party, PJM maintains the reliability of the system by monitoring the high-voltage transmission grid 24 hours a day, seven days a week, and keeps the electricity supply and demand in balance by dispatching generation on a least-cost basis.

Figure 2-1: Map of PJM Member Utilities



Source: PJM Interconnection, LLC

PJM's footprint is divided into three broad sub regions within PJM: Western, Mid-Atlantic, and Southern, as shown in Figure 2-2.

The Mid-Atlantic region, which encompasses Delaware, and most of Pennsylvania,[5] is also known as PJM East.[6] At different times of the year, there are transmission constraints into PJM East itself that limit how much electricity can be delivered to the region from the

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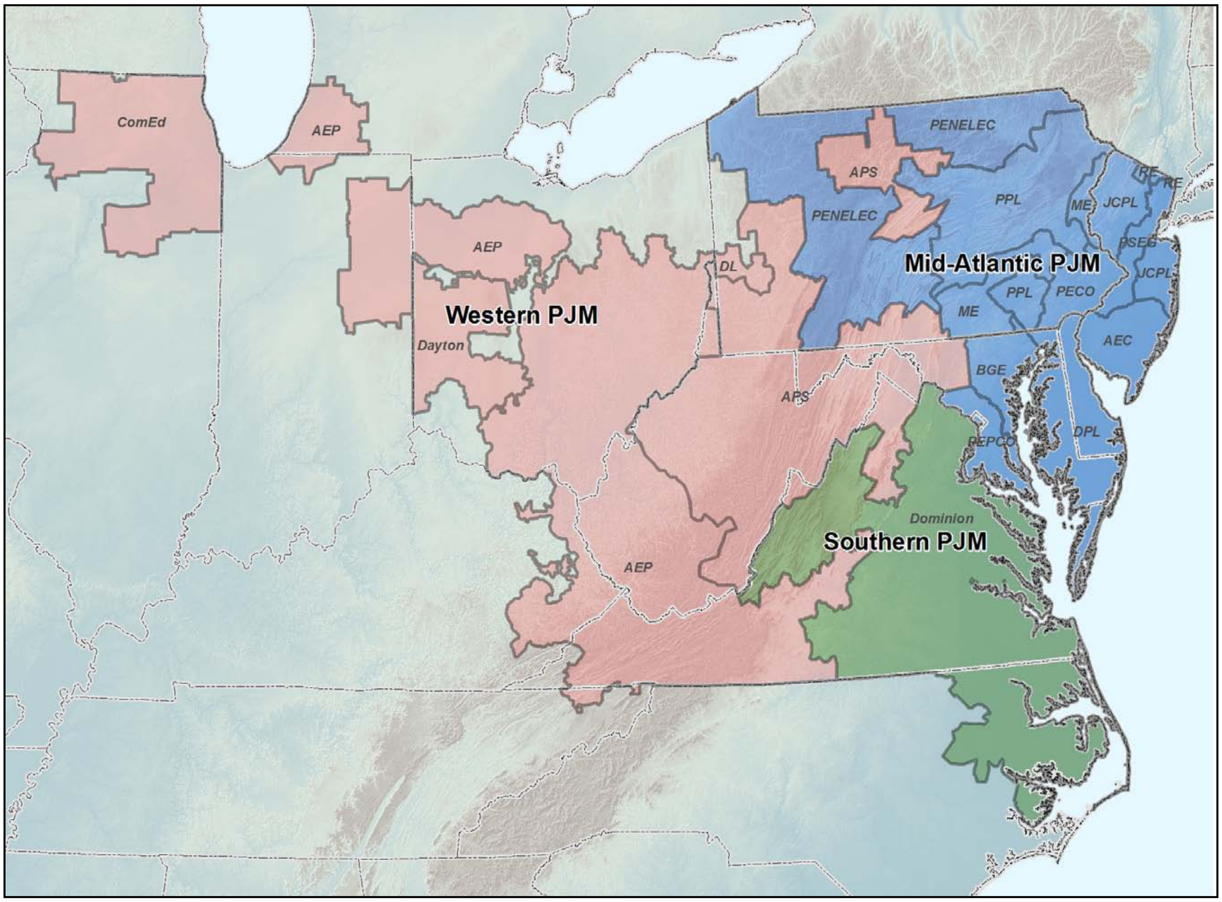
[5] The mid-Atlantic region excludes the Pennsylvania service territory of Allegheny Power. The region encompasses what is called the "Mid-Atlantic Area Council" (MAAC), which is one of the NERC reliability organizations.

[6] PJM East is sometimes referred to as "PJM Classic," as the utilities in these states formed the core of PJM before it expanded between 2002 and 2005 by adding the utilities that comprise Western PJM and Southern PJM.

Western subregion. By providing "local" generation within PJM East, specifically near Philadelphia, Limerick reduces the economic and reliability impacts of those transmission constraints into Pennsylvania, and helps lower wholesale electricity prices, saving Pennsylvania consumers hundreds of millions of dollars each year.

Figure 2-2: PJM Subregions



Source: PJM Interconnection, LLC

Because of relatively fewer generation facilities and the resulting transmission system congestion, wholesale market prices in PJM East are persistently higher than those in the western and southern regions of PJM.[7] As such, the location of Limerick makes the

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[7] For example, according to the 2010 PJM State of the Market (SOTM) Report, the congestion component of locational marginal prices in the PECO zone averaged $2.69/MWh in the day-ahead market and $2.84/MWh in the real-time market, reflecting constrained west to east transmission flows. See, 2010 SOTM, Volume II, p. 481.

electricity generated by the facility, as well as the ancillary services[8] they provide, even more valuable to PJM and retail electric consumers.

3. HOW LIMERICK REDUCES WHOLESALE ELECTRICITY PRICES IN PJM EAST

By providing over 18 million MWh of electricity annually into PJM East, and over 2,300 MW of generating capacity, Limerick helps to reduce the price of both wholesale electricity and installed capacity, which means lower electricity prices for Pennsylvania businesses and individuals.[9] To estimate the overall economic impact of Limerick's generation on wholesale electricity market prices, we developed an econometric model to determine how wholesale electricity prices in PJM East would have likely increased had Limerick's generation not been available.[10]

3.1 The PJM Wholesale Electricity Market

PJM operates two wholesale electricity markets: a day-ahead market and a real-time market. The system operator uses the day-ahead bids to determine which generation resources will be used to meet demand at the lowest possible cost the next day, while ensuring the transmission system operates safely,[11] based on the predicted electric demand. Real-time market clearing prices will typically differ slightly from the day-ahead clearing prices because: actual electric demand is never exactly equal to the day-ahead forecast; generators occasionally experience unexpected outages; and the transmission system has constraints.

In PJM, the price of electricity in any given hour (or fraction of hour) is determined by the price of the last generation unit needed to serve total load in that hour. Consumers benefit when the system uses as much low-cost power as possible, including the generation from Limerick, so that more expensive fossil-fuel units do not need to be run.

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[8] Ancillary services encompass a variety of products to ensure the system is reliable and always capable of meeting regional electricity demand. In other words, ancillary services help ensure the lights always stay on.

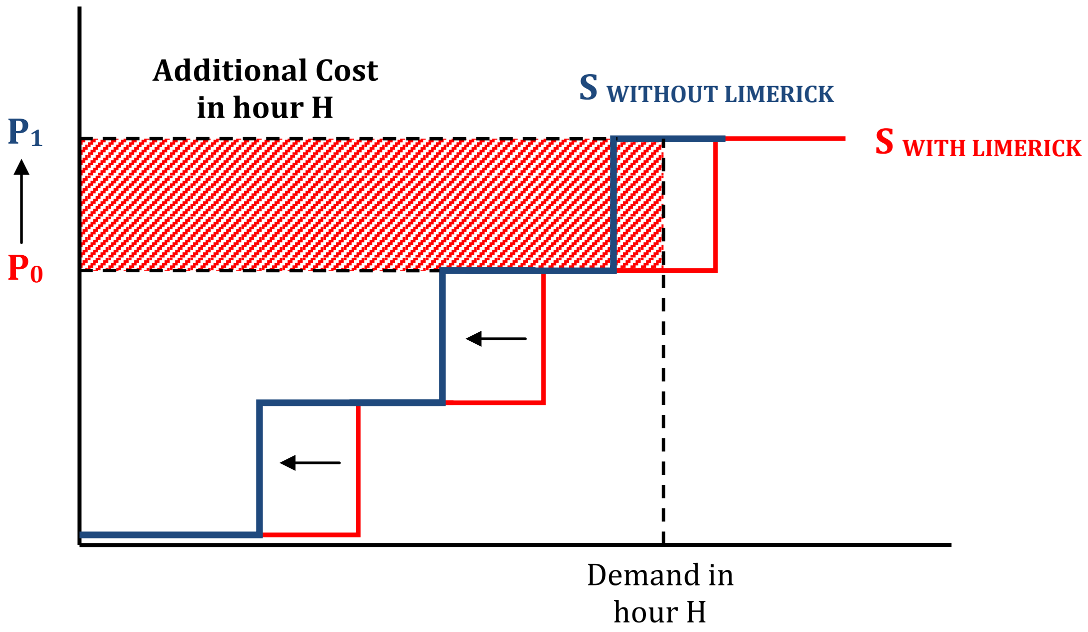
[9] In addition to acting as a clearinghouse for wholesale electricity sales, PJM implemented its Reliability Pricing Model in 2007 for installed capacity. Installed capacity, which includes both generating facilities and demand-response resources (DR), can be called on any time to ensure PJM meets peak customer demand.

[10] Appendix 1 provides a detailed description of this model.

[11] This is called "security constrained economic dispatch."

As stated earlier, PJM's wholesale electricity market, like all other markets for products and services, is based upon basic supply and demand principles. If supply decreases in the face of constant or growing demand, and constant or rising fuel costs, then prices will increase. Nuclear energy from a plant like Limerick is one of the least expensive means of producing electricity. Thus, as illustrated in Figure 3-1, the electric supply needed to replace Limerick would have to come from other more expensive generation, inevitably leading to higher wholesale and retail electricity prices for consumers and businesses alike.

Figure 3-1: Impact on PJM wholesale electricity market prices when Limerick is not available



This figure shows the generation supply curve (**S**) both with and without Limerick. At a particular hour, (H), the demand for electricity is such that the market-clearing price is $\$P_0$/MWh. Without Limerick available, the supply curve would shift up and to the left, because more expensive generating units would be needed to meet the demand in hour H. As a result, the market-clearing price would increase to $\$P_1$/MWh.

3.2 The PJM Capacity Market

In addition to reducing the wholesale price of electricity for Pennsylvania consumers, Limerick benefits consumers by providing firm generating capacity. Specifically, Limerick participates in PJM's capacity auction, which is called the "Reliability Pricing Model" (RPM). Having sufficient generating capacity available is crucial to ensure that the system can meet peak demand at any moment. That capacity is also critical for future planning, to ensure that, over the long run, there will be sufficient generation to help maintain the reliability of the overall PJM system.[12]

The genesis of capacity requirements can be traced to the 1965 Northeast blackout, which led to the formation of the North American Electric Reliability Council (NERC) followed by 10 regional reliability councils and power pools. One way to reduce future blackouts is to ensure there is enough generating capacity to meet unexpected increases in loads that could occur, for example, because of a series of extremely hot days or because of sudden loss of power caused by equipment failures.

PJM's capacity market has evolved over time into the current RPM model which began in 2007.[13] RPM is designed to obtain needed capacity at the lowest possible price using market forces, while providing clear signals to indicate when new generation is needed to meet growing customer demand. PJM holds an annual base auction, and several incremental auctions, in which generators and DR submit bids into the capacity market. The total amount of capacity selected is determined by the point where capacity supply equals capacity demand, as set by PJM based on established reliability standards.

Each base auction establishes the cleared capacity supply and the clearing price three years in advance.[14] For example, in May 2010, PJM held its capacity auctions for the 2013–14 planning year.[15] Holding the auctions three years in advance provides developers with the necessary time to build new resources or, for those bidding in DR, time to negotiate with businesses that will be called on to curtail their loads when required.

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[12] For a general discussion of the benefits provided by capacity markets, see Jonathan Lesser and Guillermo Israelivich, "The Capacity Market Enigma," *Public Utilities Fortnightly* (December 2005), pp. 38–42.

[13] PJM has had capacity requirements to ensure that peak customer demand is always met for decades. However, it was not until 2007 when an actual *market* for capacity was developed.

[14] The annual auction is called the "Base Residual Auction." PJM also conducts three incremental auctions in each planning year, "to allow for replacement resource procurement, increases (procurement) and decreases (selling excess) in resource commitments due to reliability requirement adjustments, and deferred short-term resource procurement." Source: "PJM RPM Incremental Auction FAQs," available at: http://www.pjm.com/~/media/markets-ops/rpm/rpm-auction-info/rpm-incremental-auction-faqs.ashx.

[15] PJM's "planning year" runs from July through June. A copy of the results of the 2013–14 auction report can be downloaded from PJM, at: http://www.pjm.com/markets-and-operations/rpm/~/media/markets-ops/rpm/rpm-auction-info/2013-2014-base-residual-auction-report.ashx .

Although we did not estimate the dollar impact Limerick's absence would have had on wholesale capacity prices in 2010, without the plant's capacity, those prices would have likely been significantly higher.

3.3 Estimating the Decrease in Wholesale Electricity Prices

To estimate the electricity savings provided by Limerick, we developed an econometric model using actual PJM hourly real-time market price data to determine the relationship between hourly demand and hourly prices. In essence, our model predicts the changes in market prices needed to bring supply and demand into balance if Limerick's generation were eliminated from the overall generation supply in PJM East. Additionally, our model takes into consideration the cost of replacing Limerick's output with higher priced fossil-fueled generation, primarily coal and natural gas.

The model predicted hourly market prices based on the demand for electricity and the average prices of natural gas and coal, the primary fuels used by fossil-fuel generating plants in PJM. We used hourly electricity price data from January 1, 2010 through December 31, 2010, to estimate the econometric model. Natural gas prices during this period were much lower than in 2008, when natural gas prices peaked, although higher than in 2009. For example, Henry Hub natural gas prices exceeded $13 per million Btu (MMBtu) in 2008, but by September 2009, prices had fallen to just $2/MMBtu. In July 2010, the average Henry Hub price had increased to just over $4.60/MMBtu and closed out the year at $4.19/MMBtu. For all of 2010, the average price of Henry Hub natural gas was $4.37/MMBtu.

Prices for Appalachian coal were similarly volatile, increasing from $40/ton in early 2007 to almost $150/ton in the summer of 2008, before decreasing to about $50/ton by the end of 2009. In July 2010, prices averaged just under $70/ton and, for the entire year, averaged about $66/ton.

The results of our analysis indicate that, without Limerick's generation in 2010, the cost of electricity in PJM East would have been over $2.1 billion higher. Of that total, Pennsylvania electric consumers in PJM East (roughly the eastern half of the state) would have paid an additional $880 million, based on eastern Pennsylvania electric utilities' share of PJM east loads. Moreover, that increase in cost does not include the higher costs Pennsylvania electric consumers would have paid for installed capacity.

4. IMPACTS OF LOWER ELECTRICITY PRICES ON THE PENNSYLVANIA ECONOMY

Higher-cost electricity has even more widespread impacts on the Pennsylvania economy than simply raising consumers' monthly electric bills. For example, households forced to spend more money on electricity will reduce their spending on other goods and services, affecting businesses that catered to those consumers. Similarly, businesses paying increased electric bills must either reduce their output, increase their prices, or both. Those impacts can then lead to job loss, which will in turn further reduce consumer spending, causing even greater economic losses.

Because of the interconnections among industries, and between industries and households, a change in the price of just one good or service can cause *ripple effects* throughout the Pennsylvania economy. Positive ripple effects add jobs and increase disposable income as more workers are hired, more equipment and supplies are purchased from other local businesses, more wages are paid to employees, and more taxes are paid to government entities. Conversely, negative ripple effects result in job loss and decreased disposable income. These impacts are called *multiplier effects* or *multipliers*. In other words, the impacts of higher electricity prices would "ripple" through the entire Pennsylvania economy, leading to job losses and reductions in economic output.

4.1 Tracing economic impacts through the Pennsylvania economy

To estimate multipliers and the overall economic impacts of changes to one sector of the economy, economists and regional scientists often use what are called "input-output" (I/O) models.[16] Input-output analysis traces the interdependencies of an economy, specifically the sales and purchases of goods among all of the sectors of an economy. For example, constructing a hydroelectric dam requires a significant amount of concrete. Manufacturing that concrete, however, requires firms to purchase inputs including sand, gravel, and electricity. Similarly, the turbines that generate electricity require steel, copper wire, and so forth. Moreover, construction requires the use of many workers who then spend their wages on all varieties of goods and services. An input-output framework is designed to trace all of these inter-relationships.

Figure 4-1 shows the general analytical framework for an input-output model at the individual state level.[17] In this figure, the Pennsylvania economy is broken down into three broad sectors: agriculture, manufacturing, and services. Those industries not only purchase goods and services from each other, but also purchase goods and services from out-of-state firms. Out-of-state purchases are referred to as "leakages," because the dollars are said to "leak out" from the Pennsylvania economy. Similarly, purchases of goods and services from Pennsylvania by out-of-state firms are referred to as "external demand." The total impacts

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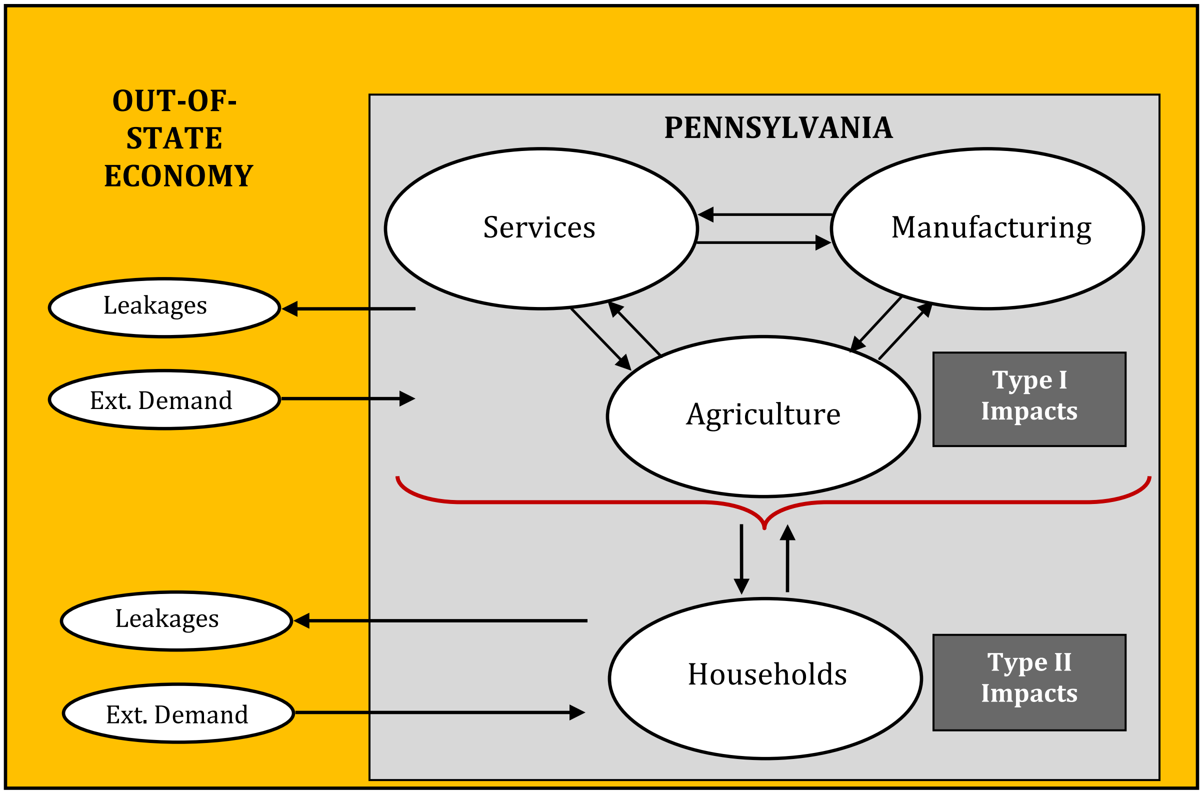
[16] W. Leontief, *Input–Output Economics*, 2nd Ed. (New York: Oxford University Press 1986).

[17] Appendix 2 provides a more detailed explanation of the input-output analysis and how we estimated the overall economic impacts of increased electric expenditures.

of business and industry on the input-output model when households are excluded are called *Type I* impacts.

Of course, individual households' expenditures also affect the economy and their impacts can be incorporated into the input-output framework. Pennsylvania businesses and industries provide employment and wages to Pennsylvania households. These households then spend a portion of that wage and salary income purchasing goods and services produced both in and out of state, including electricity. When the impacts of both businesses and households are considered, they are classified as *Type II* impacts.

Figure 4-1: Representation of the Pennsylvania Economy



Types of economic impacts

In our input-output study, we model three distinct types of economic impacts: *direct*, *indirect*, and *induced*. Direct impacts are those that are a direct result of a change in demand for a good or service. For example, Limerick purchases $35 million worth of goods and services from Pennsylvania firms every year. That $35 million expenditure is a direct impact stemming from Limerick's operation.

This direct expenditure on goods and services will ripple through the Pennsylvania economy and have indirect and induced impacts. The reason is that the businesses that

Limerick purchases from themselves must purchase goods and services as inputs that are used in producing what Limerick buys from them. For example, Limerick uses service vehicles at the plant, which require regular maintenance services that are purchased from nearby firms. These firms, in turn, must purchase motor oil, replacement parts, electricity, and so forth as part of their day-to-day operations and to provide the maintenance services that Limerick purchases from them. The purchases these firms make are called indirect expenditures and lead to indirect economic impacts.

Finally, businesses pay wages to their employees. Limerick, for example, has an annual payroll of $75 million that is paid to its employees. These employees, in turn spend a portion of the wages they receive on food, electricity, new cars, and other goods and services from businesses within the state. These expenditures made by Limerick employees are revenues that those businesses use to purchase supplies and pay wages to their employees, who then spend those wages as well. The expenditures are said to ripple through the economy.

Because of the interconnections among Pennsylvania businesses and industries, and between those businesses and industries and Pennsylvania households, higher prices for electricity would also ripple through the Pennsylvania economy. These state-wide negative ripple effects would lead to fewer jobs and reduced disposable income as workers were let go, less equipment and supplies were purchased from other local businesses, fewer wages were paid to employees, and lower tax revenues were paid to government entities. These ripple effects cause the overall economic impacts to be a multiple of the initial, direct impacts. The size of the overall impact relative to the initial direct impact is called the *multiplier effect* and the ratio itself is called a *multiplier*. The magnitude of the ripple effects and the resulting multipliers depends on the interactions among Pennsylvania businesses, industries, and households, and the amount of money that “leaks out” of the Pennsylvania economy. Our estimates of these economic impacts, the resulting multipliers, and the methodology we used to estimate them are discussed below.

Estimating the economic impacts in Pennsylvania using IMPLAN

To estimate the economic impacts of higher electricity costs on the Pennsylvania economy, we applied the widely used **IM**pact for **PLAN**ning (IMPLAN) model.[18] IMPLAN is used by numerous government agencies, at both the federal and state levels, including for example the Bureau of Land Management and the National Marine Fisheries Service.

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[18] IMPLAN was first developed in the late 1970s by the U.S. Forest service to analyze the economic impacts of different forestry policies. The current version of IMPLAN is maintained by MIG, Inc. (formerly the Minnesota IMPLAN group).

The IMPLAN model begins with the most current national transactions matrix developed by the current National Bureau of Economic Analysis Benchmark Input-Output Model. The model breaks down the U.S. economy into over 500 separate economic sectors in agriculture, manufacturing, commercial services, and government. Next, the model creates state and county-level values by adjusting the national level data, such as removing industries that are not present in a particular state or economy. The model also estimates imports using what are called *regional purchase coefficients* (RPCs). An RPC measures the proportion of the total supply of a good or service required to meet a particular industry's intermediate demands and final demands that are produced locally. The larger the RPC value, the greater the percentage of total regional demand that is met through local supplies. These RPCs are important for estimating the economic impacts of higher electricity prices, because the greater the leakages out of the Pennsylvania economy, the less the overall impacts will be in the state.[19]

4.2 Modeling the economic impacts of higher electricity costs in Pennsylvania

To model the economic impacts of higher electricity costs on the Pennsylvania economy, we assumed that businesses and consumers would reduce their purchases of other goods and services by an equivalent amount. For example, we assumed that an individual household that was forced to spend \$100 more on electricity would consequently spend \$100 less on all other goods and services they would normally purchase. We also assumed that households would continue to purchase the same proportions of those other goods and services. For example, if an individual had previously spent \$200 annually on haircuts and three times as much, or \$600, annually on clothes, the model assumes he continues to spend three times more for clothes as haircuts, but at lower levels, e.g., \$190 on haircuts and \$570 (3 x \$190) on clothes. Similarly, businesses paying more for electricity would reduce purchases of all of the other inputs they used to produce their goods and services by the same percentages, thus maintaining the same relative proportions of each.[20]

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[19] In addition to calculating standard Type I and Type II multipliers, IMPLAN can also calculate what are called "SAM multipliers." SAM stands for "Social Accounts Matrix," and is a more detailed breakdown of transactions within an economy. Specifically, whereas the typical input-output framework captures production and consumption, it leaves out some income transactions, such as taxes, savings, and transfer payments. IMPLAN allows users to capture these components as well, and thus derive what are called SAM multipliers. SAM multipliers are a form of Type II multiplier. Thus, SAM multipliers incorporate direct, indirect, and induced impacts, while accounting for the effects of savings, taxes, and transfer payments.

[20] The Leontief input-output framework assumes what are called "fixed production coefficients." This means that firms cannot substitute inputs, e.g., using more natural gas instead and less electricity, to produce the same output. The production coefficients are called "technical

Next, as summarized in Table 4-1, we used IMPLAN to estimate the changes in output, income, and jobs arising from the reductions of *in-state* expenditures on goods and services stemming from the increased cost of electricity.[21] Based on the 66.5% average RPC for all goods and services in Pennsylvania, we estimate that the $880 million increase in electricity prices would cause a further direct reduction of spending on goods and services produced in the state of $585 million ($880 million times 66.5%). Using IMPLAN, and incorporating household expenditures (i.e., Type II impacts) we determined that a $585 million decrease of in-state purchases would cause an overall reduction of $1,078 million in output in the Pennsylvania economy. As such, the *Type II output multiplier* equals $1,078 million divided by $585 million, or 1.84.[22]

Table 4-1: Estimated Type II Impacts of Higher Electricity Prices in Pennsylvania

Impact	Direct Impact	Total Impact	Multiplier
Lost Output	$585 Million	$1,078 Million	1.84
Lost Jobs	3,785†	10,525	2.78

† - based on a weighted average of 6.47 jobs/million$ of lost output.

As the table shows, had the generation from Limerick been unavailable in 2010, the higher electricity prices that Pennsylvania consumers would have paid, and the resulting decreases in their expenditures on other goods and services, would have led to an overall reduction of $1,078 million in output in the Pennsylvania economy and over 10,500 fewer jobs,[23] for a *Type II employment multiplier* of 2.78. If Limerick were shut down, resulting in the loss of 826 full-time jobs at Limerick and $75 million in payroll, and a reduction of $35 million of in-state purchases of goods and services used at the plant, the adverse economic impacts would be even higher. The direct lost output within the state would increase to

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(cont.)

coefficients" in the I/O modeling framework. Although this assumption does not hold in the long-run, it is reasonable for short-run impact studies.

[21] The IMPLAN model shows that 66.5% of the purchases made by Pennsylvania households and businesses are in-state. Thus, about 33% of the adverse economic impacts would fall outside of Pennsylvania. We have not included those out-of-state impacts in Table 4-1.

[22] If household impacts are excluded from an input-output analysis, the resulting multipliers are called *Type I* multipliers. If households are included, they are called *Type II* multipliers. Excluding households, the Type I output multiplier is 1.37.

[23] The lost jobs value is based on full-time equivalents, and therefore in units of "job-years."

over $660 million,[24] resulting in a total output loss of almost $1.2 billion, and total job losses of over 11,900 (826 employees plus 10,525 jobs lost because of reduced in-state spending plus 597 jobs lost because of reduced wages and in-state purchases of supplies), as shown in Table 4-2.

Table 4-2: Estimated Type II Impacts of Higher Electricity Costs in Pennsylvania Including Lost Limerick Employment and in-state Purchases

Impact	Direct Impact	Total Impact	Multiplier
Lost Output	$662 Million	$1,178 Million	1.78
Lost Jobs	5,083†	11,948††	2.35

† - based on a weighted average of 6.47 jobs/million$ of lost output, plus the loss of 826 plant employees.

†† - based on 826 lost plant jobs plus 10,525 lost jobs from reduced output elsewhere in state, plus loss of 597 total jobs because of reduced in-state purchases of equipment and lost wages.

Over time, these economic impacts would gradually diminish, as firms and households adjusted to the higher electricity prices. Firms would adjust how they produced goods and services by reducing the amount of electricity needed to produce each unit of output,[25] by taking steps such as investing in more energy efficient equipment, or using natural gas instead of electricity. However, such adjustments are never “free:” a company investing in new energy efficient motors, for example, will necessarily forgo other investments that it might have otherwise made had the price of electricity not increased. This is what economists refer to as “opportunity cost.”

5. ENVIRONMENTAL BENEFITS OF LIMERICK

If Limerick’s output had been unavailable in 2010, not only would Pennsylvania’s supply of baseload generation have decreased substantially, but air pollution would have increased significantly. The first step to estimating the increase in air pollution that would result from replacing Limerick’s output is to determine the mix of fossil-fuel generation that would replace Limerick in every hour that the facility generated electricity.

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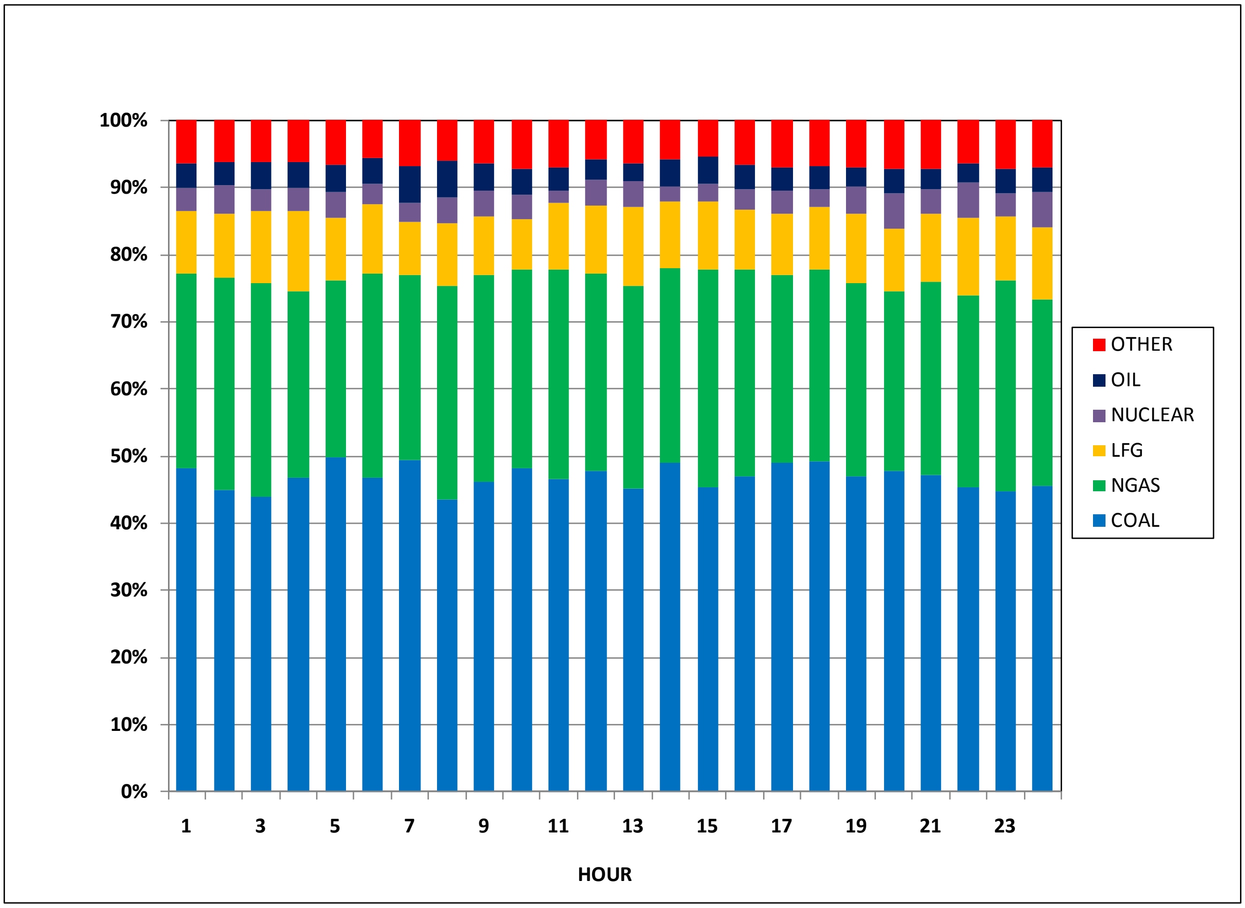
[24] This includes loss of the $35 million in goods and services purchased locally by the plant, plus reductions in in-state purchases because of the loss of the $75 million payroll. The loss of payroll would reduce in-state purchases by about $42 million, based on a 15% payroll tax rate applied to wage and salary payments, and in-state purchases of 66.5% of total expenditures. Hence, the total is $585 million + $35 million + {$75 million x (1-0.15) x 0.665} = $662 million.

[25] In other words, the technical coefficient for electricity would decrease.

To perform our analysis, we used data published by the Independent Market Monitor (IMM) which shows the type of generating unit on the margin in each hour of the year,[26] combined with individual generating plant emissions data published by the U.S. EPA as part of its eGRID database for generating plants in PJM.[27]

The type of generation on the margin during each hour is shown in Figure 5-1.

Figure 5-1: Marginal Generation Fuel Type by Hour in PJM (2010)



As Figure 5-1 indicates, coal was the marginal fuel in about 47% of all hours in 2010. Similarly, natural gas (NGAS and landfill gas, or LFG) was the marginal fuel in about 40% of all hours. Fuel oil was the marginal fuel in about 3.7% of all hours, while nuclear was the

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[26] Monitoring Analytics, monthly fuel reports. Available at: http://www.monitoringanalytics.com/data/marginal_fuel.shtml

[27] U.S. EPA, Emissions and Generation Integrated Resource Database (eGRID), http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2010_Version1-0.zip.

marginal fuel in 3.6% of all hours. During the remaining 6.5% of all hours, a variety of other generating resources, including wind, hydroelectric, and imports were on the margin.

Using the information on marginal fuel types in every hour, we next determined avoided emissions. Specifically, we estimated the average emissions rates (pounds/MWh) for coal-fired, oil-fired, and natural gas-fired generating plants in PJM, then combined these emissions rates with the average percentages for each fuel type on the margin in PJM in 2010. The emissions rates are shown in **Table 5-1**.

Table 5-1: Estimated Emission Rates by Fuel Type, PJM Generating Units (Pounds/MWh)

Generator Fuel Type	NOx	SO2	CO2
Coal†	3.07	9.21	2,108
Fuel Oil††	0.56	0.17	953
Natural Gas†††	1.62	4.53	922

†–Bituminous coal. †–average of light oil, heavy oil, and kerosene. ††† - includes landfill gas (LFG). Source: EPA, eGRID 2010.

By combining the average marginal fuel types for each hour for 2010 with Limerick's average annual generation in each hour, we estimated the emissions reductions for SO2, NOx, and CO2 attributable to Limerick, as shown in Table 5-2.

Table 5-2: Limerick Total Avoided Emissions (tons)

Generator Fuel Type	NOx	SO2	CO2
Coal†	13,596	40,822	9,336,938
Fuel Oil††	2,093	642	3,544,082
Natural Gas†††	568	1,588	323,418
TOTAL	**16,257**	**43,053**	**13,204,439**

As Table 5-2 shows, we estimate that Limerick reduced NOx emissions by over 16,000 tons, SO2 emissions by over 43,000 tons, and CO2 emissions by over 13 million tons. Based on data published by EPA, the latter is equivalent to the CO2 emissions produced by over 2.5 million cars.[28]

Although gasoline-powered cars and trucks do not emit SO2,[29] they do emit NOx. According to data published by the U.S. Energy Information Administration, fossil-fuel generating plants emitted 780,000 tons of SO2 and 181,000 tons of NOx in 2008. By comparison, the current standard for light-duty cars and trucks is about 0.07 tons over the first ten years or 100,000 miles.

6. CONCLUSIONS

This report has provided an analysis of the economic contributions made by the Limerick Nuclear Generating Station to the Pennsylvania economy, as well as its environmental benefits. As the report has shown, Limerick is a major contributor to the Pennsylvania economy providing over $200 million in direct and indirect economic contributions annually in addition to reduced electricity prices of about $880 million annually. If Limerick were shut down, the economic impacts of the plant closure and the resulting higher-cost electricity would ripple through the entire Pennsylvania economy, leading to the loss of almost 12,000 jobs. Moreover, if Limerick's output were replaced by fossil-fuel generating plants, air pollution emissions would increase significantly, adding over 13 million tons of CO2 to the air, as well as an additional 43 thousand tons of sulfur dioxide and 16 thousand tons of oxides of nitrogen.

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[28] The EPA estimates that the average car produces 5.2 tons of CO2 per year.

[29] Diesel-powered cars and trucks do emit SO2, because of the sulfur in diesel fuel. New emissions standards have drastically reduced the sulfur content in diesel fuel.

APPENDIX 1

Econometric Model and Estimation of Annual Changes in Electric Expenditures in PJM East

The model is designed to estimate day-ahead LMPs in every hour, based on changes in hourly loads and fuel prices that, absent transmission constraints, determine the marginal unit setting the LMP in any given hour. Thus, the model is effectively mapping out the intersection of PJM East supply and demand in any given hour.

Model Structure

To develop an econometric model of hourly PJM East prices, we began with the factors that were likely to influence locational market prices, including the price of natural gas, the price of coal, and dummy variables to capture the few hours where market clearing prices reached "extreme" levels, likely as a combination of high demand and operational constraints. In addition, we included a dummy variable for those hours (days) when the day-ahead price of natural gas delivered on the Texas-East M3 system was more than \$3/MMBtu, to reflect to reflect a lack of gas availability when natural gas is diverted from electric generators to meet retail customer heating loads.

After evaluating a number of alternative model structures, we settled on the following model:[30]

$$\begin{aligned} LN(LMP_t) &= \beta_0 + \beta_1 \cdot LOAD_t + \beta_2 \cdot LOAD_t^2 + \beta_3 \cdot LOAD_t^3 + \beta_4 \cdot PGAS_t \\ &\quad + \beta_5 \cdot PCOAL + \beta_6 \cdot DUM\_TEM3HH_t \\ &\quad + \beta_7 \cdot DUM\_LMP250_t + \varepsilon_t \end{aligned} \qquad \text{(A1-1)}$$

where:

$LN(LMP_t)$ = Natural logarithm of PJM East LMP (\$/MWh), in hour t

$LOAD_t$ = PJM East load (in gigawatts), in hour t

$PGAS_t$ = Day-ahead Texas-East M3 natural gas price (\$/MMBtu), in hour t

$PCOAL_t$ = Historic daily forward coal price for NAPP 3.0 coal

DUM_TEM3HH_t = Dummy variable, equal to 1 when the Texas East M3 gas price exceeds the Henry Hub price by more than \$3/MMBtu

DUM_LMP250_t = Dummy variable equal to 1 when the PJM East LMP is greater than \$250/MWh in hour t (to reflect system constraints)

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[30] Because this is a log-linear model, those hours where the market-clearing price was below zero were dropped from the regression.

The model was estimated for the 12-month period, January 2010 – December 2010, to allow for different marginal responses that could arise because of changes in the generation mix and changes in transmission infrastructure.

Because the fitted model showed evidence of significant autocorrelation, we re-estimated the model using a four-term ARIMA structure. Under this error structure, we assumed that

$$\varepsilon_t = \rho_1 \varepsilon_{t-1} + \rho_2 \varepsilon_{t-2} + \rho_3 \varepsilon_{t-3} + \rho_4 \varepsilon_{t-4} + \rho_{12} \varepsilon_{t-12} + \nu_t$$

After estimating similar models for each year, we calculated the change in predicted market prices in each hour without Limerick. When Limerick was not generating power, the predicted market price increased. Thus, from equation (A-1), the change in the *log* of the predicted price in a given hour, $\Delta LN(\widehat{P}_t)$, equals:

$$\begin{aligned} \Delta LN(\widehat{P}_t) = {} & \widehat{\beta}_1 \cdot (LOAD_t - LOAD\_LIMERICK_t) + \widehat{\beta}_2 \cdot (LOAD_t^2 - LOAD\_LIMERICK_t^2) \\ & + \widehat{\beta}_3 \cdot (LOAD_t^3 - LOAD\_LIMERICK_t^3) \end{aligned} \tag{A1-2}$$

Adding equation (A-2) to the log of the predicted price from equation (A1-1) provides the log of the new predicted price without generation from Limerick, $\widehat{P}_t^{No\_Lim}$. Thus,

$$LN(\widehat{P}_t^{NO\_LIM}) = LN(\widehat{P}_t) + \Delta LN(\widehat{P}_t) \tag{A1-3}$$

Therefore, the new predicted price in any hour will equal

$$\widehat{P}_t^{NO\_LIM} = \widehat{P}_t \cdot e^{\Delta LN(\widehat{P}_t)} \tag{A1-4}$$

The net change in the predicted price in any given hour,

$$\Delta \widehat{P}_t = \widehat{P}_t^{NO\_LIM} - \widehat{P}_t = \widehat{P}_t \cdot e^{\Delta LN(\widehat{P}_t)} - \widehat{P}_t = \widehat{P}_t \cdot (e^{\Delta LN(\widehat{P}_t)} - 1) \tag{A1-5}$$

Using the results of (A1-5), the total change in wholesale electricity expenditures in a given year, ΔEXP_{YEAR}, equals

$$\Delta EXP_{YEAR} = \sum_{t=1}^{T} \Delta \widehat{P}_t \cdot LOAD_t \tag{A1-6}$$

Where:

ΔP_t = Change in the predicted market-clearing price in hour t
$LOAD_t$ = Observed load in hour t
T = 8,760 in 2010

APPENDIX 2

Input-Output Modeling Framework[31]

An input-output framework begins with observed transaction data for a particular region. For example, the IMPLAN model is constructed from data at the national, state, and county levels. The transactions are typically converted into dollar amounts, as that makes tracing economic flows much easier, since dollars are a uniform measure.

We assume that the economy is made of up of numerous sectors, e.g., manufacturing, mining, agriculture, services, government, and foreign trade. To construct an input-output table, we record how the output produced (supplied) by a given sector, such as steel, is purchased by (demanded) the other industry sectors (who then use those purchased inputs to manufacture other goods), plus external sales to government and consumers. Thus, if there the economy consists of N industries, the output of an individual industry, X_n, will be purchased by the other N–1 industries, as well as used by itself, and sold to final consumers. Thus,

$$X_k = z_{k,1} + z_{k,2} + z_{k,3} + \ldots + z_{k,N} + Y_k \tag{A2-1}$$

where the $z_{i,n}$ are sales to each industry n, and Y_n equals sales for final demand (i.e., to consumers, the government, and for export). Since we have N industries, we can write the entire set of flows as

$$\left[\begin{array}{l} X_1 = z_{1,1} + z_{1,2} + \ldots + z_{1,k} + \ldots + z_{1,N} + Y_1 \\ X_2 = z_{2,1} + z_{2,2} + \ldots + z_{2,k} + \ldots + z_{2,N} + Y_2 \\ \vdots \\ X_k = z_{k,1} + z_{k,2} + \ldots + z_{k,k} + \ldots + z_{k,N} + Y_k \\ \vdots \\ X_N = z_{N,1} + z_{N,2} + \ldots + z_{N,k} + \ldots + z_{N,N} + Y_N \\ \\ \end{array}\right] \tag{A2-2}$$

Each column of coefficients on the right-hand side of equation (A2-2), i.e.,

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[31] For a far more detailed discussion, see Leontief, *op. cit*. See also, R. Miller and P. Blair, *Input-Output Analysis: Foundations and Extensions*, (Englewood Cliffs, NJ: Prentice-Hall 1985), Chp. 2.

$$\begin{bmatrix} z_{1,k} \\ z_{2,k} \\ \vdots \\ z_{n,k} \\ \vdots \\ z_{N,k} \end{bmatrix}$$

represents the purchases from industry sector k to the N–1 other industry sectors, and to itself ($z_{k,k}$). In other words, industry k purchases inputs from all of the other industries to produce output X_k. When all of the N different columns are combined , they create an *input-output table*, with each selling sector a different row, and each purchasing sector a different column, as shown in Table A2-1.

Table A2-1: An Input-Output Table

		Purchasing industry sector					
		1	**2**	**...**	**K**	**...**	**N**
	1	$Z_{1,1}$	$Z_{1,2}$	**...**	$Z_{1,k}$		$Z_{1,N}$
Selling Industry Sector	**2**	$Z_{2,1}$	$Z_{2,2}$	**...**	$Z_{2,k}$		$Z_{2,N}$
	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$
	k	$Z_{k,1}$	$Z_{2,k}$	**...**	$Z_{k,k}$		$Z_{N,k}$
	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$
	N	$Z_{N,1}$	$Z_{N,2}$	**...**	$Z_{N,k}$		$Z_{N,N}$

Although the input-output table above does not incorporate all of the inter-industry sales and purchases, it does not account for the remainder of the economy. For example, final demand includes sales to consumers, state, local, and the federal government, investment, and exports. Moreover, in addition to buying outputs from other industries, each industry pays wages to its employees (W), pays for government services (in the form of taxes), pays for capital (in the form of interest payments, I), and profits. Together, these components are called *value-added*. On top of that, each sector imports goods and services from outside the economy. For example, if building a new high-voltage transmission line requires buying substation equipment from Germany, then the input-output model of the U.S. would consider that an import.

The input-output framework assumes that production coefficients are fixed. This means that there are specific quantities of inputs required to produce a given output. Thus, building a car—any car—is assumed to take (say) 2000 pounds of steel, 100 pounds of rubber, 200 pounds of glass, and so forth. Obviously, this assumption of fixed production coefficients does not hold true entirely—the amount of materials needed to build a large pick-up truck is greater than that needed to built a subcompact car—but for estimating short-run impacts, the overall assumption is reasonable: building more cars and trucks will clearly require more steel, producing more steel will require more iron ore, and so forth.

Because the input-output framework assumes fixed production coefficients (called a "Leontief production function"), the necessary inputs needed to produce a unit of output are all constant. If we divide the purchases made by industry k from every industry, i.e., the $z_{i,k}$, to produce output X_k, we derive the *technical coefficients*, $a_{i,k}$, for industry k. In other words,

$$a_{i,k} = \frac{Z_{i,k}}{X_k} \qquad \text{(A2-3)}$$

If we substitute equation (A2-3) into equation (A2-2), we obtain:

$$\begin{bmatrix} X_1 = a_{1,1}X_1 + a_{1,2}X_2 + \ldots + a_{1,k}X_k + \ldots + a_{1,N}X_N + Y_1 \\ X_2 = a_{2,1}X_1 + a_{2,2}X_2 + \ldots + a_{2,k}X_k + \ldots + a_{2,N}X_N + Y_2 \\ \vdots \\ X_k = a_{k,1}X_1 + a_{k,2}X_2 + \ldots + a_{k,k}X_k + \ldots + a_{k,N}X_N + Y_n \\ \vdots \\ X_N = a_{N,1}X_1 + a_{N,2} + \ldots + a_{N,k}X_k + \ldots + a_{N,N}X_N + Y_N \end{bmatrix} \qquad \text{(A2-4)}$$

What equation (A2-4) tells us is that some of the output produced by an industry is sold to all other industries and used in fixed quantities to produce those industries' outputs, and the remainder is sold as final demand to consumers, government, and as exports. As a final step, we can isolate the final demands for the output from each industry, Y_k. Thus,

$$\begin{bmatrix} X_1 - a_{1,1}X_1 + a_{1,2}X_2 + \ldots + a_{1,k}X_k + \ldots + a_{1,N}X_N = Y_1 \\ X_2 - a_{2,1}X_1 + a_{2,2}X_2 + \ldots + a_{2,k}X_k + \ldots + a_{2,N}X_N = Y_2 \\ \vdots \\ X_k - a_{k,1}X_1 + a_{k,2}X_2 + \ldots + a_{k,k}X_k + \ldots + a_{k,N}X_N = Y_n \\ \vdots \\ X_N - a_{N,1}X_1 + a_{N,2} + \ldots + a_{N,k}X_k + \ldots + a_{N,N}X_N = Y_N \end{bmatrix} \qquad \text{(A2-5)}$$

Equation (A2-5) lies at the heart of the economic impact analysis, because it allows us to answer the question, "If the demand for the output of industry k increased, by how much would the output of all of the other industries change?" For example, building a new high-voltage transmission line would increase the demand for concrete, steel, and so forth. How will those increased demands ripple through the Pennsylvania economy and what will be the final changes in output levels in all other industries, as well as the increased labor output (i.e., jobs) and income?

To answer this sort of question, we solve equation (A2-5) for each of the X_i. This requires a bit of matrix algebra. It turns out that the solution can be written as

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y} \tag{A2-6}$$

where

$$\mathbf{A} = \begin{bmatrix} a_{1,1} \cdots a_{1,N} \\ a_{2,1} \cdots a_{2,N} \\ \vdots \\ a_{N,1} \cdots a_{N,N} \end{bmatrix}, \qquad \mathbf{X} = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_N \end{bmatrix}, \qquad \mathbf{Y} = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_N \end{bmatrix}$$

The matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is called the *Leontief inverse*. By changing the level of final demand in vector **Y** and knowing the technical coefficients, we can determine the flows through the economy.

There are three types of economic impacts typically evaluated in an input-output study: *direct*, *indirect*, and *induced*. Direct effects are those that are a direct result of an increase in demand for good k. For example, building a new high-voltage transmission line will require concrete for the tower foundations. Thus, the demand for concrete will increase. That is a *direct* impact. Increasing the demand for concrete, however, will require concrete manufacturers to increased their purchases of all of the inputs used to manufacture concrete, including sand, gravel, electricity, and so forth, thus increasing the demand for all of those inputs. Thus, the *direct* increase in the demand for concrete *indirectly* increases the demand for all of these other products. Finally, all of these manufacturers pay wages to employees. Those employees, in turn spend a portion of their wages on food, electricity, new cars, and so forth. As a result, we say the resulting consumer spending from households *induces* further increases in demand, and thus additional economic impacts.

Because of the interconnections among industries and between industries and households, an increased demand for just one good or service is said to cause *ripple effects* throughout the economy. These ripple effects lead to additional jobs and increases disposable income as workers are hired, equipment and supplies are purchased from other local businesses, wages are paid to employees, and taxes are paid to government entities. These impacts are called *multiplier effects* or *multipliers*. For example, if the demand for concrete increases by \$1 million and the overall impact on the PA economy is \$2 million, then the output multiplier equals \$2 million/\$1 million = 2.0. We can also calculate jobs and income multipliers. For example, if 100 workers are hired to construct a transmission line, and the overall ripple effects lead to 50 new jobs created as a result, the employment multiplier will equal 150/100 = 1.5.

Estimating economic impacts

Ripple effects act like waves bouncing off walls. Eventually, each subsequent round of impacts decreases in magnitude, just like a wave bouncing off walls eventually subsides. The speed at which these ripple effects diminish, and the overall magnitude of multipliers, depends on what are called *leakages* out of an economy. For example, not all of the materials needed to build the transmission line will be purchased from Pennsylvania companies. Moreover, some of the workers hired to construct the project may be from outside the state. Furthermore, Pennsylvania workers who are hired will not spend all of their wages within the state, but will instead buy goods and services from neighboring states, too. As we discuss in the sections that follow, assumptions about *leakage rates*, i.e., what fraction of spending occurs outside Pennsylvania, are crucial in estimating the overall economic impacts to the state.

Calculating multipliers[32]

Multipliers are calculated from the Leontief inverse matrix defined previously. For example, suppose we have an economy with just two industries, with the following technical coefficients matrix.

$$\mathbf{A} = \begin{bmatrix} 0.15 & 0.25 \\ 0.20 & 0.05 \end{bmatrix} \tag{A2-7}$$

What this means is that, \$1 of additional output of industry 1 purchases \$0.15 from itself and \$0.20 from industry 2. The remaining \$0.65 goes for valued added – wages, taxes, and profits. Similarly, to produce \$1 of additional output, industry 2 purchases \$0.25 from industry 1, \$0.05 from itself, and the remaining \$0.70 is value added. It turns out the Leontief inverse matrix (ignoring the value added impacts) is

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[32] For a much more detailed discussion, see Miller and Blair, *op. cit*, from which these examples are drawn.

$$(\mathbf{I}-\mathbf{A})^{-1}=\begin{bmatrix}1.254 & 0.33\\ 0.264 & 1.122\end{bmatrix} \tag{A2-8}$$

The values in the Leontief inverse provide the output multipliers, by adding up each column. Specifically, if there is a $1 increase in final demand for the output from industry 1, then the total increase in demand for output from industry 1 is $1.254 - $1 for the increase in final demand, and $0.254 for inter-industry and intra-industry use. There is also an *indirect* increase in demand of $0.264 of industry 2 for inter-industry and intra-industry use. Thus, if we sum down the first column, a $1 increase in demand for industry 1 leads to a total increase in output of $1.254 + $0.264 = $1.518. The output multiplier is thus $1.518/$1 = 1.518. Because we are not considering households in this example, this output multiplier is called a *Type I* multiplier.

Next, we consider household impacts, such as from wages paid to households. Suppose that industry 1 pays $0.30 in wages per dollar of output and that industry 2 pays $0.25 in wages per dollar of output. By incorporating these payments into the technical coefficients matrix, we can determine the direct, indirect, and *induced* impacts from increased output. So, we rewrite the technical coefficients matrix as follows:

$$\mathbf{A}=\begin{bmatrix}0.15 & 0.25 & 0.05\\ 0.20 & 0.05 & 0.40\\ 0.30 & 0.25 & 0.05\end{bmatrix} \qquad (\mathbf{I}-\mathbf{A})^{-1}=\begin{bmatrix}1.365 & 0.425 & 0.251\\ 0.527 & 1.348 & 0.595\\ 0.570 & 0.489 & 1.289\end{bmatrix} \tag{A2-9}$$

The new technical coefficients matrix **A** now contains 3 rows and 3 columns. The 2x2 matrix of values in the top left hand corner is the original matrix (with values highlighted in red). The third column represents households. So, in the example, households spend $0.05 per dollar buying items from industry 1, $0.40 per dollar buying items from industry 2, and $0.05 buying items from within the household sector. (The remainder is spent paying taxes and for investment.). The third row shows that industry 1 spends $0.30 per dollar on wages, while industry 2 spends $0.25 per dollar on wages.

When we calculate the new Leontief inverse $(\mathbf{I}-\mathbf{A})^{-1}$, the first to notice is that the previous coefficients (the top-left 2x2 matrix) are all larger. This is because we are now including household demand impacts. Now, the output multiplier for industry 1 is the sum of the first column [1.365, 0.527, 0.570], or 2.462. Thus, for every $1 increase in demand in industry 1, total output in the economy increases by $2.462. In matrix notation, the output multiplier for sector j is:

$$\mathbf{i}_j \bullet (\mathbf{I}-\mathbf{A})^{-1} \bullet \mathbf{i}_j', \tag{A2-10}$$

where $\mathbf{i}_j = \begin{bmatrix} 0 & \cdots & 1_j & \cdots & 0 \end{bmatrix}$.[33]

We can calculate the household income multiplier for industry 1 in several ways. The first is to treat household spending as outside our model and estimate impacts using the Type 1 multipliers. To do that, we go back to the initial Leontief inverse in equation (A2-8) and multiply the household income coefficients in **A** for our two industries (the third row) by the first column in the Leontief inverse, and add the results, i.e.,

$$H_1 = (0.30)(1.254) + (0.25)(0.264) = 0.442$$

What this means is that, for every \$1 increase in demand for the output of industry 1, total household income increase by \$0.442 because of the direct and indirect economic impacts on output. Thus, the *Type 1 multiplier* is \$0.442/\$0.30 = 1.47.

If we include the economic impact caused by households also spending money in the economy, the result is called a *Type II multiplier*. To do this, we use the new **A** and $(\mathbf{I}-\mathbf{A})^{-1}$ matrices shown above. For industry 1, we calculate the total household income change, including the within-household sector impacts and divide by \$0.30 that industry 1 pays directly to households in the form of wages. Thus, we have

$$H_1' = (0.30)(1.365) + (0.25)(0.527) + (0.05)(0.57) = 0.570$$

and the multiplier is H_1'/0.30 = \$0.57/\$0.30 = 1.9. Note also that the overall household impact, \$0.57 is just the value in the last row of the Leontief inverse matrix for industry 1.

Finally, we can also estimate *employment multipliers*, following the same approaches we have previously outlined. Only this time, the multipliers do not reflect dollar changes, but changes in employment. To do this, one determines the number of employees (in full-time equivalents) per dollar of output in each industry. For example, suppose for each million dollars of output produced in industry 1, 300 employees are required, and that in industry 2, 400 employees are used per million dollars of output. This translates to values of 0.003 and 0.004 employees per dollar in industries 1 and 2, respectively. Similarly, assume the household sector requires 100 employees per million dollars of output, or 0.001 employees per dollar. Then, using the Leontief inverse matrix in equation (9), we calculate the total employment impact for industry 1 as

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[33] In other words, $\mathbf{i}_i$ is a 1xN unit vector having value 1 for industry j. The term $\mathbf{i}_j'$ is called the *transpose* of $\mathbf{i}_i$, and is a Nx1 column vector.

$$E_1' = (0.003)(1.365) + (0.004)(0.527) + (0.001)(0.570) = 0.000572$$

Then, using the same approach as for calculating the Type II income multipliers, we can calculate the Type II employment multiplier for industry 1 as E_1'/0.0003 = 1.907.

The IMPLAN Model

The **IM**pacts for **PLAN**ning (IMPLAN) model was first developed in the 1970s by the U.S. Forest service to analyze the economic impacts of different forestry policies. The current version of IMPLAN is maintained by the University of Minnesota IMPLAN group. IMPLAN provides a detailed breakdown of the U.S. economy, with over 500 separate economic sectors. IMPLAN is widely used by numerous government agencies, including at the federal and state levels.

The IMPLAN model begins with the most current national transactions matrix developed by the current National Bureau of Economic Analysis Benchmark Input-Output Model. Next, the model creates state and county-level values by adjusting the national level data, such as removing industries that are not present in a particular state or economy. The model also estimates imports using what are called *regional purchase coefficients* (RPCs). RPCs measure the proportion of the total supply of a good or service required to meet a particular industry's intermediate demands and final demands that are produced locally. The larger the RPC value, the greater the percentage of total regional demand that is met through local supplies.

In addition to calculating standard Type I and Type II multipliers, IMPLAN can also calculate what are called "SAM multipliers." SAM stands for "Social Accounts Matrix," and is a more detailed breakdown of transactions within an economy. Specifically, whereas the typical input-output framework captures production and consumption, it leaves out some income transactions, such as taxes, savings, and transfer payments. IMPLAN allows users to capture these components as well, and thus derive what are called SAM multipliers.[34] SAM multipliers are a form of Type II multiplier. Thus, SAM multipliers incorporate direct, indirect, and induced impacts, while accounting for the effects of savings, taxes, and transfer payments.

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[34] For complete discussion of how SAM multipliers are derived, see G. Alward, "Deriving SAM multipliers using IMPLAN," paper presented at the 1996 National IMPLAN Users Conference, Minneapolis, MN, August 15–17, 1996, 1996. Available at: http://implan.com/v3/index.php?option=com_docman&task=doc_download&Itemid=138&gid=127.

Estimating the economic impacts of higher electricity prices

To estimate the overall economic impacts of the higher wholesale electricity prices and higher capacity market costs, we assume a short-run price elasticity of zero. That is, we assume consumers will not, initially, reduce their electric consumption in response to the slightly higher electricity prices they faced. Since consumer income is assumed to be fixed in the short run, this implies consumers must reduce their expenditures on all other goods and services (including savings and investment) by an equivalent amount.

Similarly, we assume that in-state businesses would react to the increased price of electricity by reducing their total output such that their aggregate production expenses remained unchanged. This assumption is consistent with the assumption of fixed production coefficients in the Leontief model. It also assumes that businesses would not be able to pass on the increased production costs to consumers.

Estimating the total impacts on state output

With these assumptions, we estimate the overall change in output as follows. First, we calculate a weighted-average *regional purchase coefficient* for output in the Pennsylvania economy, excluding electric power. A regional purchase coefficient (RPC) equals the fraction of local demand for a good or service that is satisfied from local production. For example, in Pennsylvania, 36% of all ready-mix concrete was purchased from in-state manufacturers, based on 2008 data. The weighted RPC, RPC_{PA}, equals the sales-weighted average of the individual sector RPCs, excluding the electric generation sector. Thus,

$$RPC_{PA} = \frac{\sum_{i=1, i\neq k}^{N} Q_i \cdot RPC_i}{\sum_{i=1, i\neq k}^{N} Q_i} \qquad \text{(A2-11)}$$

Similarly, we calculate the weighted-average SAM output multiplier, $\bar{M}_{PA}^{output}$, using the output from each industry as the individual industry weights. Thus, using equation (A2-10) for the output multiplier for industry j, we have

$$\bar{M}_{PA}^{output} = \sum_{i=1, j\neq k}^{N} Q_i \cdot \{\mathbf{i}_i \bullet (\mathbf{I} - \mathbf{A})^{-1} \bullet \mathbf{i}_i'\}, \qquad \text{(A2-12)}$$

The total impact on output in the state thus equals the weighted RPC times the weighted output multiplier, times the estimated increase in total electric expenditures. Thus,

$$\Delta Q_{PA}^{TOT} = \Delta Q_{ELEC} \cdot RPC_{PA} \cdot \bar{M}_{PA}^{output} \tag{A2-13}$$

Estimating the total impact on state employment

We follow a similar procedure to estimate the total impacts on state employment arising from the higher electric expenditures, with the additional step of estimating the weighted average employment per million dollars of output, using the employment multipliers calculated by IMPLAN. Thus, weighted jobs per million dollars of output

$$\bar{J}_{PA} = \sum_{i=1, i \neq k}^{N} Q_i \cdot J_i \,/\, Q_{PA}^{TOT} \,, \tag{A2-14}$$

where J_i is jobs per million dollars of output in industry j. The overall weighted jobs multiplier is[35]

$$\bar{M}_{PA}^{jobs} = \sum_{i=1, i \neq k}^{N} Q_i \cdot J_i \{\mathbf{i}_i \bullet (\mathbf{I} - \mathbf{A})^{-1} \bullet \mathbf{i}_i'\} \,/\, Q_{PA}^{TOT} \tag{A2-15}$$

And so, the total impact on jobs in the state, equals

$$\Delta J_{PA}^{TOT} = (\Delta Q_{ELEC} \cdot RPC_{PA}) \cdot (\bar{J}_{PA} \cdot \bar{M}_{PA}^{jobs}) \tag{A2-16}$$

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[35] The jobs multiplier is just the output multiplier weighted by jobs per million dollars of output.