The Value of U.S. Energy Innovation and Policies Supporting the Shale Revolution

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Executive Summary

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The classic effects of innovation are improvements in productivity, which lower costs and prices and increase production. Energy innovations—and the policies that support them—have similar effects and ultimately reduce prices for American households and businesses. This CEA report describes the causes and consequences of growth in oil and natural gas extraction from shale and similar geologic formations, with a focus on effects on consumers. We first discuss the dramatic rise in productivity and its effects on cost, production, and price. Second, we estimate the consumer savings brought by shale-driven declines in energy prices. Third, we assess total and shale-related changes in emissions in the United States. Lastly, we consider the effects of contrasting approaches to energy policy taken by U.S. States.

From 2007 to 2019, innovation in shale production brought an eight-fold increase in extraction productivity for natural gas and a nineteen-fold increase for oil. These productivity gains have reduced costs and spurred production to record-breaking levels. As a result, the United States has become the world's largest producer of both commodities, surpassing Russia in 2011 (for natural gas) and Saudi Arabia and Russia in 2018 (for oil). CEA estimates that greater productivity has reduced the domestic price of natural gas by 63 percent as of 2018 and led to a 45 percent decrease in the wholesale price of electricity. Shale production has also reduced the global price of oil by 10 percent as of 2019.

By lowering energy prices, we estimate that the shale revolution saves U.S. consumers $203 billion annually, or $2,500 for a family of four. Nearly 80 percent of the total savings stem from a substantially lower price for natural gas, of which more than half comes from lower electricity prices. Oil accounts for the other roughly 20 percent of the savings, most of which are transportation sector savings on fuel costs. Because low-income households spend a larger share of their income on energy bills, lower energy prices disproportionately benefit them: shale-driven savings represent 6.8 percent of income for the poorest fifth of households compared to 1.3 percent for the richest fifth of households. These consumer savings are in addition to economic benefits linked to greater employment in the sector.

The shale revolution has also reduced energy-related Greenhouse Gas (GHG) and particulate emissions through changes in the composition of electricity generation sources. We estimate that from 2005 to 2017, the shale revolution lowered energy-related GHG emissions by 527 million metric tons per year, or 9 percent of GHG emissions in 2005. This contributed to a greater decline in GHG and particulate emissions (relative to the size of the economy) in the United States than in the European Union over that period.

The Trump Administration's deregulatory energy policy follows earlier Federal deregulatory policies that helped to spur the shale revolution. By limiting unnecessary constraints on private innovation and investment, the Administration's policy supports further unleashing of the country's abundant human and energy resources. It contrasts with policies that expand government control and restrictions on productivity and innovation, which some States have adopted. New York, for example, has banned shale production and stymied new pipeline construction. New York's policies have led to falling natural gas production in the State, greater reliance on energy produced elsewhere, and higher energy prices. New York's failure to approve new pipelines causes consumers in New York and New England to pay an estimated $2 billion more in energy costs each year, or $233 for a family of four. Moreover, New York's rate of GHG emissions reduction has been less than the rate in the neighboring State of Pennsylvania, which has allowed shale production to flourish and now produces more than twice the energy that it consumes.

Introduction

To meet needs for heat, light, power, and transportation, U.S. consumers typically spend $1.4 trillion dollars annually, or roughly 7 percent of total GDP, on energy goods. Innovation that lowers the price of energy goods can therefore bring large and widespread savings for U.S. households and businesses.

The classic effects of innovation are improvements in productivity, which lower costs and prices and increase production. Energy innovations—and the policies that support them—have similar effects and ultimately reduce prices for American households and businesses. This CEA report describes the causes and consequences of growth in oil and gas extraction from shale and similar geologic formations, a development often referred to as the shale revolution. We first describe the dramatic rise in productivity and its effects on costs and prices. Second, we estimate the consumer savings brought by shale-driven declines in energy prices. Third, we assess total and shale-related changes in emissions in the United States. Lastly, we consider the effects of starkly different energy policies taken by States, which have the primary responsibility of regulating extraction. To our knowledge, this report is the first to estimate the combined U.S. consumer savings from growth in shale oil and natural gas production or the distribution of savings across household income groups.

From 2007 to 2019, innovation in shale production brought an eight-fold increase in extraction productivity for natural gas and a nineteen-fold increase for oil. These productivity gains have reduced costs and spurred production to record-breaking levels. As a result, the United States has become the world's largest producer of both commodities, surpassing Russia in 2011 (for natural gas) and Saudi Arabia and Russia in 2018 (for oil). CEA estimates that greater productivity has reduced the domestic price of natural gas by 63 percent as of 2018 and led to a 45 percent decrease in the wholesale price of electricity. Higher production from shale has also reduced the global price of oil by 10 percent as of 2019.

By lowering energy prices, we estimate that the shale revolution is saving U.S. consumers $203 billion annually, or $2,500 for a family of four. Nearly 80 percent of the savings stem from a substantially lower price for natural gas, of which more than half comes through an effect on electricity prices. Oil accounts for the other roughly 20 percent of the savings, most of which are transportation sector savings on fuel. Because low-income households spend a larger share of their income on energy bills, lower energy prices disproportionately benefit them: shale-driven savings represent 6.8 percent of income for the poorest fifth of households compared to 1.3 percent for the richest fifth of households. The consumer savings are in addition to economic benefits linked to production such as job creation, payments to landowners, and revenues for State and local governments, which this report describes only briefly.

The shale revolution has also reduced energy-related Greenhouse Gas (GHG) and particulate emissions through changes in the composition of electricity generation sources. We estimate that over the 2005-2017 period, the shale revolution lowered energy-related GHG emissions by 527 million metric tons per year, or 9 percent of emissions in 2005. This contributed to a greater decline in GHG emissions (relative to the size of the economy) in the United States than in the European Union over the same period. The same is also true of particulate emissions, which have declined much more in the United States (57 percent) than in the European Union (41 percent).

The Trump Administration's deregulatory energy policy follows the vein of earlier Federal deregulatory policies that helped to spur the shale revolution. By limiting unnecessary constraints on private innovation and investment, the Administration's policy supports further unleashing of the country's abundant human and energy resources. It contrasts with policies that expand government control and restrictions on productivity and innovations, which some States have adopted. New York, for example, has banned hydraulic fracturing, which is an integral part of developing shale resources, and stymied new pipeline construction. These policies have led to falling natural gas production in the State, greater reliance on energy produced elsewhere, and higher energy prices. New York's failure to approve new pipelines causes consumers in New York and New England to pay an estimated $2 billion more in energy costs each year, or $233 for a family of four. Moreover, New York's rate of GHG emissions reduction has been less than the rate in the neighboring State of Pennsylvania, which has allowed shale production to flourish and now produces more than twice the energy that it consumes.

Unleashing Innovation: Market Pricing, Resource Access, and Freedom to Innovate

Growth in extraction of oil and natural gas from shale and similar geologic formations—often referred to as the shale revolution—is arguably the most consequential energy development in the last half century. Its far-reaching consequences are in part because fossil fuels, principally oil and natural gas, account for 80 percent of U.S. energy consumption[1] (EIA 2019b). Most oil

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[1] The International Energy Agency estimates that 82 percent of U.S. total primary energy supply (TPES) was accounted for by fossil fuels in 2018 (IEA 2019).

goes to fuel the planes, trains, and automobiles of the transportation sector while most natural gas generates electric power or heat for industry and households.

Since at least the late 1970s, geologists knew that shale and other low-permeable formations contained prodigious amounts of natural gas. For decades, methods to profitably extract these resources eluded the industry, much of which pursued easier-to-access resources in the United States and abroad. Although various countries have abundant shale resources, entrepreneurs and engineers working in the United States' innovation-friendly context first unlocked the potential of shale. This entrepreneurship would eventually bring large savings to consumers and environmental benefits relative to the status quo of energy sources used.

The shale revolution came after major deregulatory changes in the governance of natural gas pricing and distribution. Three major deregulatory actions—the 1978 Natural Gas Policy Act, the Federal Energy Regulatory Commission's 1985 Open Access Order, and the 1989 Natural Gas Wellhead Decontrol Act—liberalized access to pipelines and increased the role of market forces in determining prices paid to natural gas producers. Earlier price controls discouraged production and exploration, leading to supply shortages. Once freed to move with supply and demand, wellhead prices increased, encouraging more innovation that eventually lowered prices (MacAvoy 2008). Prices, however, would begin to increase again in the late 1990s and early 2000s.

Higher prices justified taking innovative risks on new methods and geologic formations, and private ownership of underground resources made it easy for firms to access these resources and experiment in diverse locations. The United States is unique because the private sector—homeowners, farmers, businesses—own the majority of the subsurface mineral rights. This system allows private owners to grant access to energy firms through lease contracts, which can be for one-tenth of an acre or ten-thousand acres (Fitzgerald 2014). As a result, energy firms do not have to navigate cumbersome central government bureaucracy to begin accessing subsurface resources. Although firms must still abide by U.S. Federal and State regulations, gaining the right to access resources is straightforward–they just need to adequately compensate the owner of the relevant acreage.

The shale revolution has many roots,[2] but among firms the most important is arguably Mitchell Energy. In the 1980s and 1990s, Mitchell Energy, which had long-term contracts to sell its

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[2] Wang and Krupnick (2015) discuss Federal Government policies that may have aided Mitchell Energy as it experimented in the Barnett and generally conclude that subsidies, tax credits, tax-preferred business structure, and research and development played a secondary role. The Federal Government subsidized research to aid development of shale gas in the East but because of geologic differences, the results had limited transferability to the Barnett. Moreover, an early tax credit aimed at stimulating production of natural gas from unconventional sources expired in 1992, well before Mitchell's breakthroughs in the early 2000s.

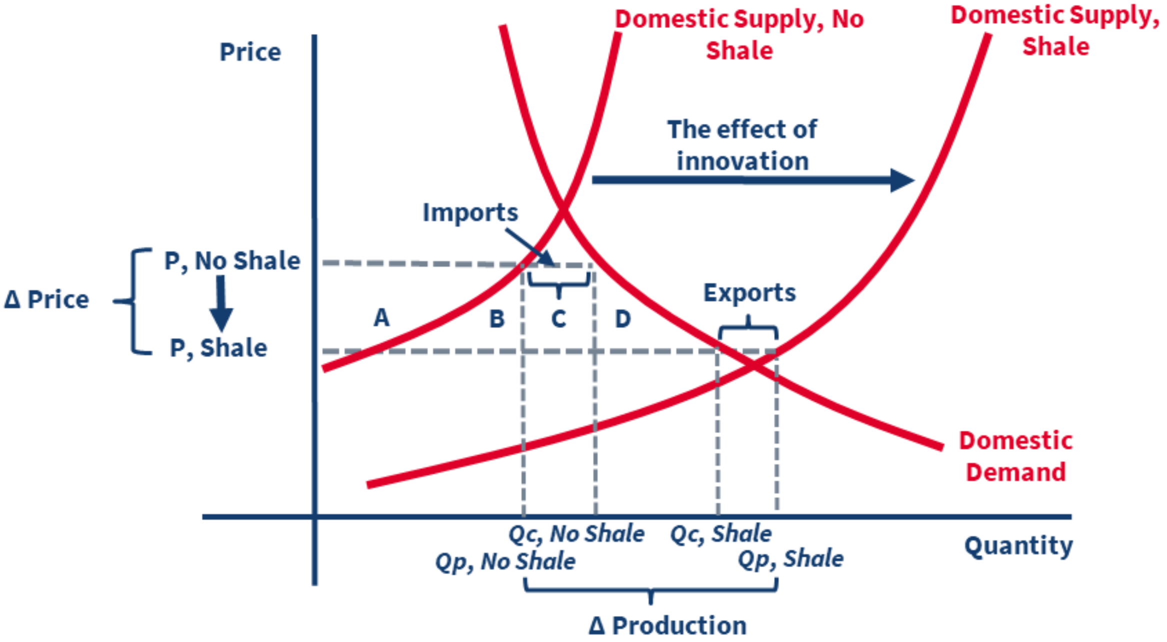
natural gas, experimented with methods to coax natural gas from a Texas geologic formation known as the Barnett Shale. Consistent commercial success emerged in the early 2000s when Devon Energy acquired Mitchell Energy. This acquisition accelerated the merger of two complementary technologies. Devon had considerable experience drilling horizontal wells, which have a horizontal portion at the bottom of a vertical portion, while Mitchell Energy had more experience with using liquids and sand under high pressure to release gas from rock, a stimulation technique known as hydraulic fracturing (Wang and Krupnick 2015). Promising results from Devon's wells, coupled with rising natural gas prices, spurred a drilling boom in the Barnett Shale. Thus, the number of well permits issued in the Barnett grew from less than 300 in 2000 to more than 4,000 in 2008. The revolution had begun.

The shale revolution may not have been sustained if it were not for continued innovation by scores of engineers, geologists, and entrepreneurs who refined and adapted methods to draw oil from Western North Dakota and Southern Texas as well as natural gas from Appalachia in the Eastern United States. Persistent innovation and opportunity for its diffusion has transformed energy markets, with considerable implications for consumers and the environment.

The Effects of Innovation: Productivity, Prices, and Production

Innovation raises productivity and lowers production costs, allowing firms to lower prices. This dynamic corresponds to the textbook case of an outward shift in the domestic supply curve, as shown in Figure 1, for the case of natural gas. The shift means that firms produce more at every price level than they did prior to innovation, which lowers the market equilibrium price, shown on the vertical axis in Figure 1 as a change in P, while increasing the quantity produced, shown on the horizontal axis as the change in Qp. The lower price stimulates an increase in consumption, shown on the horizontal axis as the change in Qc.

Figure 1. Innovation in Natural Gas Production



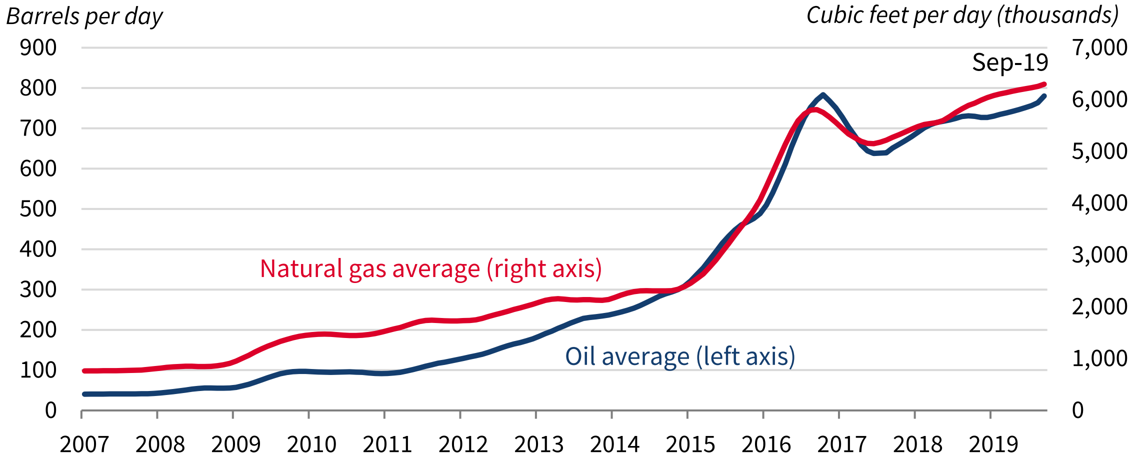
Because of imports and exports of natural gas, the market price is affected by the global price and does not occur at the intersection of domestic supply and domestic demand. Prior to shale, domestic consumption exceeded domestic production, leading to imports, as shown in Figure 1 as the difference between domestic production and consumption prior to shale. After shale, domestic production exceeds domestic consumption, leading to exports.

The Impact on Productivity

Horizontal drilling and hydraulic fracturing made the development of shale and other low-permeable formations economical. In the last decade, all growth in onshore oil and gas production has come from the development of these formations. One measure of innovation and productivity gains by energy producers is the quantity new wells are producing relative to the time it took to drill them, which the Energy Information Administration tracks for all major shale formations. This measure, known as new-well production per drilling rig, is defined as the total production of wells recently brought into production divided by the number of drilling rigs recently in operation.

New well production per rig increased by more than eight-fold between 2007 and 2019 for key shale gas regions and by over nineteen-fold for key shale oil regions. Particularly strong growth has occurred in the last five years for both oil and gas (Figure 2).[3] The recent growth highlights how energy firms have continued to improve upon the earlier breakthroughs of shale pioneers.

Figure 2. Productivity Gains: New-Well Production per Rig in Shale-Rich Regions, Oil and Natural Gas, 2007–19



Sources: Energy Information Administration (EIA); CEA calculations.
Note: New-well production is the total production from oil (or gas) wells that are in their first month of production. The rig count is the number of active oil (or gas) drilling rigs two months prior. The data correspond to seven shale-rich regions included in the EIA's Drilling Productivity Report.

The productivity gains in production per rig stem from firms drilling wells more quickly, thus generating greater production from each new well per unit time. Across regions and over time, the number of days needed to drill a well has fallen (EIA 2016), and the average production from a well's first month has grown (Energy Information Administration 2018). The improvements come partly from firms drilling wells with longer horizontal portions, and from putting more wells per pad—both of which allow each well and pad to access more oil and gas.

Greater productivity reduces the cost of producing each barrel of oil or cubic feet of natural gas. Lower unit costs lead to a lower breakeven price, which is the price needed to cover the costs of drilling and operating an oil or gas well. Figure 3 shows an estimated breakeven price based on modeling of production costs in different regions.[4] From 2014 to 2019, the breakeven

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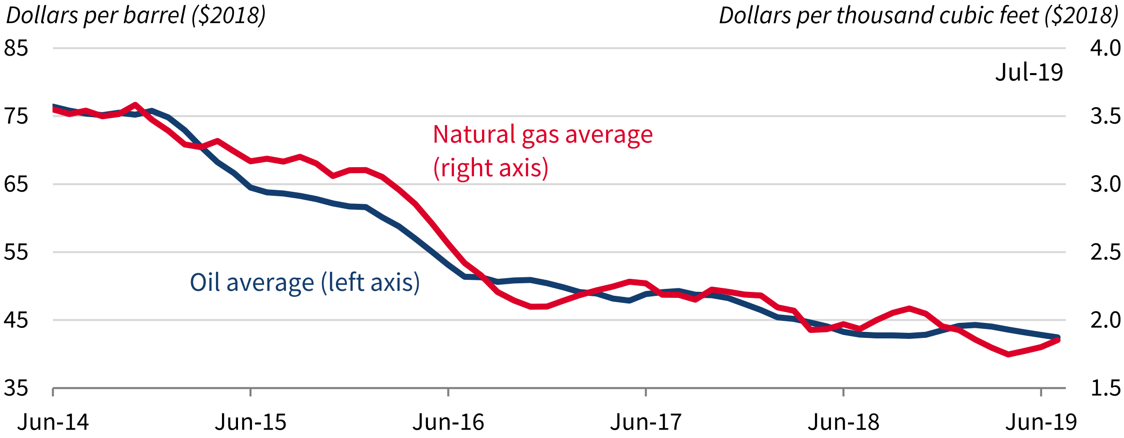
[3] The sharp 2016 rise in productivity in 2016 largely reflects firms deciding to operate fewer drilling rigs (because of very low prices) and focus on bringing wells already drilled into production. This can be seen by a sharp decline in drilled but uncompleted wells in 2016. Similarly, a rise in drilled but uncompleted wells in 2017 helps explain the apparent slowdown in productivity in that year. See (EIA 2019a) for estimates of drilled but uncompleted wells.

[4] The breakeven price, calculated by BTU Analytics, is best interpreted as the price needed to justify drilling another well, assuming that the energy firm already holds the necessary acreage. The price for a given period is calculated based on historical production data and projections of future production to model revenue and costs

price for natural gas (averaged across key shale formations) fell by 45 percent; for oil, it fell by 38 percent. The link between productivity—as measured by new-well production per rig in operation—and breakeven prices is direct. Well operators typically lease drilling rigs, paying as much as $26,000 per day, so finishing a well in half the time yields considerable savings. Similarly, higher volumes of initial production return cash more quickly to the firm and can mean greater lifetime production from the well.

Figure 3. Gains in Productivity Lower Breakeven Prices Across Key Shale Formations, 6-Month Moving Averages, 2014–19



Sources: Bloomberg; BTU Analytics; CEA calculations.

Note: Breakeven prices include the cost of drilling and operating a well and bringing the resource to market, including royalties, taxes, and gathering and compression costs. Oil average is the average price between Bakken Formation, Denver Basin, Eagle Ford, and Permian Basin; Natural gas average is the average price between Marcellus-Utica and Haynesville. Values adjusted to 2018 dollars using the Consumer Price Index (CPI-U).

The Impact on Prices and Production

In its Annual Energy Outlook, the Energy Information Administration (EIA) projects energy-related outcomes for the coming decades. The projections incorporate detailed information and assumptions on resource reserves, emerging technologies, new policies, and numerous other relevant trends. The difference between projected and actual outcomes provides one measure of the surprise and disruption brought by the shale revolution. This difference does

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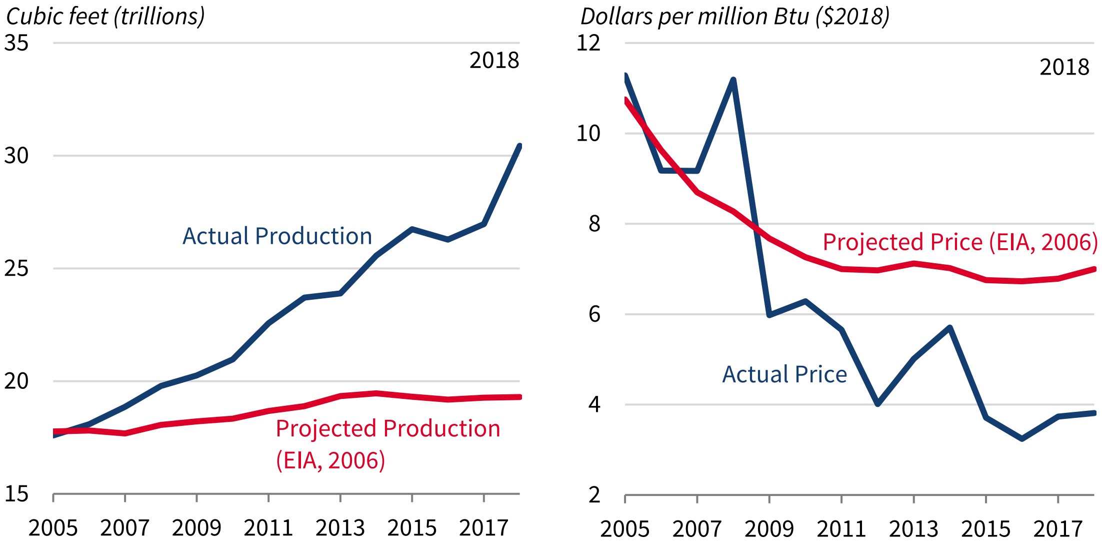
for every well brought into production in the period. This analysis assumes a discount rate of 10 percent and a well life of 240 months. It is not based on energy firm calculations of their own breakeven costs and excludes potential costs that energy firms may incur such as interest payments on debt and costs to acquire their acreage.

not necessarily isolate the shale revolution's contribution because markets may have evolved differently than expected for reasons other than shale.

The Annual Energy Outlook first included the term "shale gas" in 2008. Two years earlier, in 2006, the EIA projected that natural gas production in the Lower 48 States would rise gradually and reach 19 trillion cubic feet by 2018. Actual dry gas production for the Lower 48 States reached more than 30 trillion cubic feet in 2018, 58 percent higher than projected, and now greatly exceeds that of any other country. The production growth was not because of higher-than-expected prices. To the contrary, prices in 2018 were 46 percent lower than projected (Figure 4).

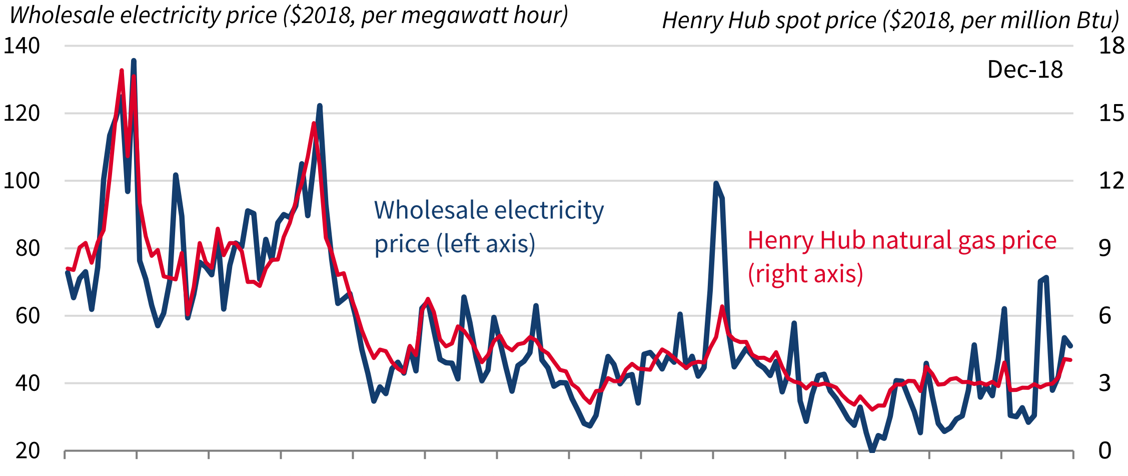
Figure 4. Natural Gas Actual vs. Projected Prices and Production, 2005–18



Sources: Energy Information Administration (EIA); CEA calculations.
Note: Projections are from the EIA 2006 Annual Energy Outlook (AEO). Prices are adjusted to 2018 dollars using the consumer price index (CPI-U). Production is for Lower 48 States, excluding Alaska and Hawaii.

The unexpected production growth and price decline of natural gas spilled over to electricity markets. Wholesale electricity prices oscillated around $80 dollars per megawatt hour over the 2005-2008 period but then dropped markedly as the price of natural gas fell. Although natural gas-fired generators have accounted for less than one third of electricity generating in recent years, they play an outsized role in influencing prices in competitive wholesale electricity markets. This is because such generators are often the marginal generator of electricity, and their operators can quickly adjust output in response to the market with relative ease, making their costs and bid prices an important determinant of the market price of electricity. Figure 5 shows the close tracking of wholesale natural gas and electricity prices and several studies have documented a strong causal effect of natural gas prices on wholesale electricity prices (Linn, Muehlenbachs, and Wang 2014; Borenstein and Bushnell 2015).

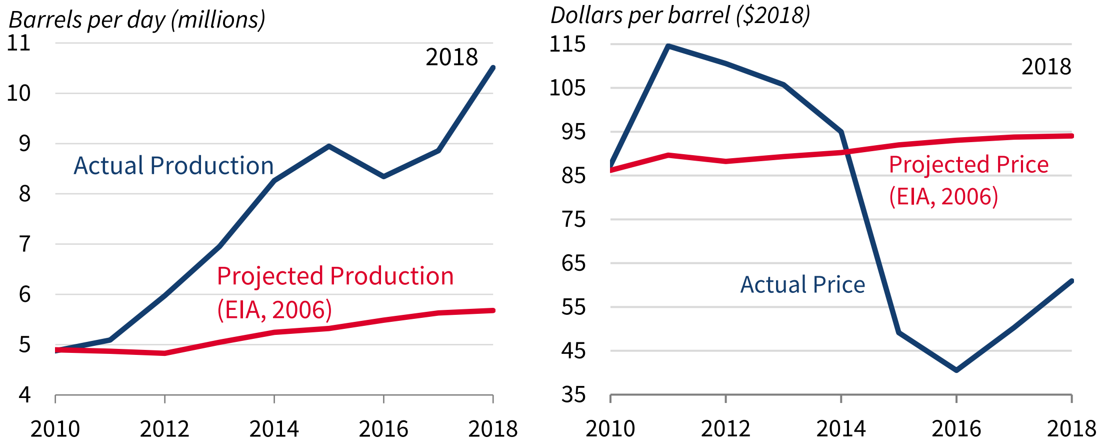
Figure 5. U.S. Monthly Wholesale Electricity Average Price and Henry Hub Natural Gas Spot Price, 2005–18



Sources: Energy Information Administration (EIA); Intercontinental Exchange; CEA calculations.
Note: Henry Hub natural gas spot price is sourced from the EIA. Wholesale prices were weighted by volume across weeks and eight wholesale electricity hubs.

Turning to oil, the difference between projected and actual oil production is even starker than the case of natural gas. Actual production in the Lower 48 States in 2018 exceeded the production projected by the EIA in 2011 by 85 percent, leading the United States to surpass Russia and Saudi Arabia to become the top global oil producer. Some of the difference between actual and projected production stems from greater-than-expected oil prices in the first half of the 2010-2018 period. The benefit of oil sector innovation, however, is still evident: since 2015, actual prices have been below projected prices while production has greatly exceeded projections (Figure 6).

Figure 6. Actual vs. Projected U.S. Crude Oil Production and Imported Prices, 2010–18



Sources: Energy Information Administration (EIA); CEA calculations.
Note: Projections are from the EIA 2011 Annual Energy Outlook (AEO). Prices adjusted to 2018 dollars using the Consumer Price Index (CPI-U). Imported crude prices are the refiners average acquisition cost for imported crude oil. Production is for Lower 48 states, excluding Alaska and Hawaii.

The Impact of the Shale-Induced Decline in Energy Prices

A simple supply and demand framework permits estimating how much energy prices have fallen because of the shale revolution as opposed to other factors that have changed over time. For natural gas, we draw from Hausman and Kellogg (2015), who look at market effects of shale gas over the 2007-2013 period. Their analysis centers on estimating the price of natural gas in a world without the shale revolution, noting that the actual change in price before and after the emergence of shale is not necessarily the causal effect of shale because the demand curve could have shifted. As a result, they estimate a natural gas demand and supply curve for 2007 and for 2013. The price of natural gas in the no-shale scenario is then estimated as the price at the intersection of the 2007 supply (pre-shale) curve and the 2013 demand curve.[5] See Hausman and Kellog (2015) for details on estimating the shale-driven price effect. Our primary modifications to their analysis are to use 2018 as the end year (not 2013) and to use more recent estimates of the supply elasticity of natural gas from Newell, Prest, and Vissing (2019).

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[5] Both prices are estimated by finding the price that solves a similar basic equation: Quantity Supplied (P) + Net Imports (P) = Residential Demand (P) + Commercial Demand (P) + Industrial Demand (P) + Electric Power Demand (P), where P is the price of natural gas. The demand and supply curves are assumed to take the form $Q = A \cdot (P + markup)^{\eta}$, where η is an elasticity. The net import function is assumed to be linear in price and is estimated using data from 2000-2018.

We also estimate the effect of lower natural gas prices on wholesale electricity prices. Natural gas plays a unique role in the electricity sector. In many parts of the United States with competitive wholesale electricity markets, natural-gas-fired plants generated the marginal unit of electricity sold. As a result, a decline in their costs lowers the market price of electricity, meaning that all electricity generators, regardless of their fuel source, receive a lower price. Likewise, all buyers, regardless of who provides their electricity, pay a lower price. Linn, Muehlenbachs, and Wang (2014) studied the effect of the shale-driven decline in natural gas prices on electricity prices and found that across wholesale market hubs, a 1 percent decrease in the price of natural gas lowers the price of electricity by 0.72 percent. To estimate the shale-driven change in the wholesale price of electricity, we therefore multiply the shale-driven percent change in the price of natural gas (described in the prior paragraph) by 0.72.

For estimating the effect of shale oil on prices, we consider two surges in shale oil production, with the second surge associated with product cuts by the Organization of the Petroleum Exporting Countries (OPEC). The first wave is defined by Kilian (November 2008 through August 2015) and the second we define as January 2017 through May 2019. For the first wave, we draw from Kilian (2017) who estimates the Brent crude oil price absent U.S. shale oil development. For the second wave, we take the Killian effect from the end of the first wave and apply it to the change in U.S. shale oil production in the second wave after taking into account the production cuts among OPEC countries since 2016.

We estimate that in a no-shale scenario, the price of natural gas would be $7.79 per Mcf, which is given by the intersection of the 2007 natural gas supply curve and the 2018 demand curve. With the shale-driven outward shift in the supply curve, the price falls to $2.87 per Mcf, a 63 percent decrease. Put differently, natural gas prices in 2018 were 63 percent lower than they would have been if the shale revolution had never occurred. This is roughly the same percentage change in the Henry Hub price of natural gas over the 2007-2018 period.

Based on the estimates by Linn, Muehlenbachs, and Wang (2014), the lower price of natural gas implies that shale gas led to a 45 percent decrease in the wholesale price of electricity as of 2018. The smaller percentage decline in the price of electricity is expected because the price of natural gas only represents a fraction of the total cost of generating a unit of electricity from natural gas. The estimated decline is also consistent with wholesale price data from the Energy Information Administration. In real terms, the weighted-average wholesale price across market hubs fell by 44 percent from 2007 to 2018.

For oil, Kilian (2017) estimates the first shale oil wave reduced the global oil price by roughly $5.00 per barrel by August 2015. Extending his analysis to the second wave of production growth from shale, we estimate that the additional production further cut $1.29 per barrel by

May 2019, giving a total price drop of $6.29 per barrel. This represents a 10 percent decline in the 2018 price of oil relative to what it would be if the shale revolution had never occurred.

Innovation-Driven Consumer Savings and Environmental Benefits

Consumer Savings

Lower energy prices can benefit consumers in diverse ways—through lower bills for heating or lighting, less spending at the gas pump, and lower prices for goods or services that require considerable energy inputs such as airline travel or building materials. The standard approach to estimating the total consumer benefit from a price decline is to calculate the savings for those consuming prior to the price decline, whose value is represented by the rectangle area formed by A, B, and C in Figure 1, and the savings on additional consumption spurred by the price decline, represented by the area D.[6] We take this approach for oil, multiplying the shale-induced change in the price of oil ($6.29 per barrel) with the pre-shale quantity consumed (about 7.0 billion barrels annually) and adding it to the one-half of the product of the price change and the price-induced change in consumption (0.1 billion barrels).

We modify this approach for natural gas to account for the spillover effects in the electricity market. First, we estimate savings using the standard approach described above and following Hausman and Kellogg (2015), who break total demand in its sectoral components, including the electricity sector. Second, we adjust downward the electricity-sector savings by multiplying it with the share of electricity consumed in regulated markets. Lastly, we add the savings from competitive electricity markets, which we calculate in the standard manner using the natural gas-driven change in wholesale electricity prices. The appendix provides details on calculating consumer savings across sectors and household income groups.

By lowering energy prices, the shale revolution is saving U.S. consumers $203 billion annually, or an average of $2,500 for a family of four. Nearly 80 percent of the savings stem from a substantially lower price for natural gas, of which more than half comes through lower electricity prices (Figure 7). The large decline in the price of natural gas, and therefore large savings, is because domestic supply has overwhelmed domestic demand, and capacity to

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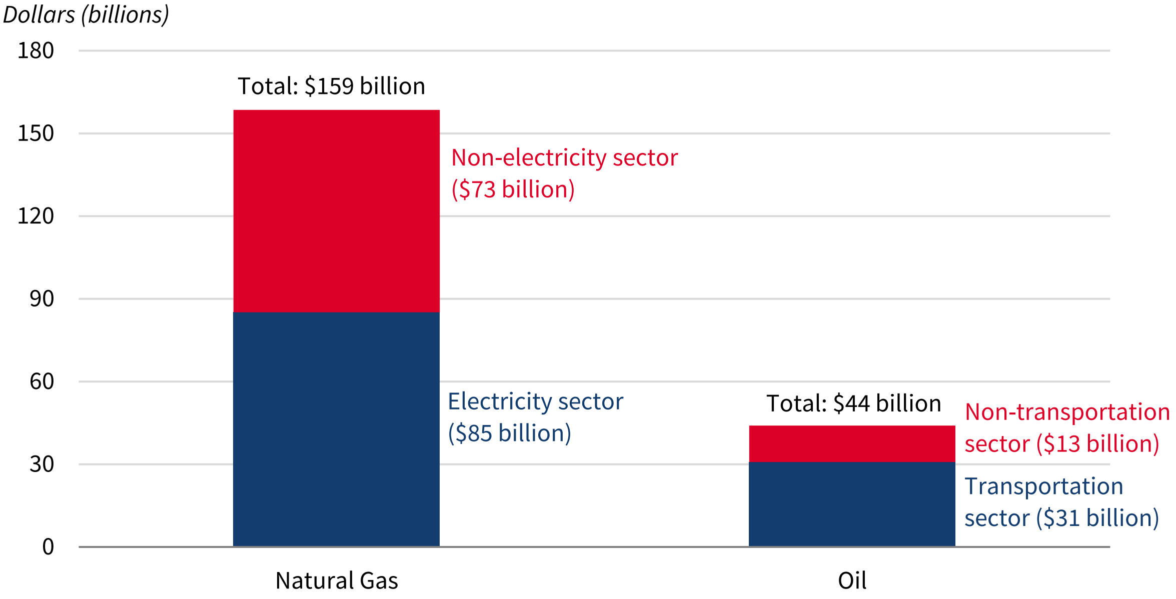
[6] The supply shift and price change will also affect producer surplus (not shown in the figure), which is the difference between revenue and cost across all units produced and all producers. Whether producers benefit from innovation (as measured by producer surplus) depends in large part on how much prices fall and quantities increase. It is likely that there is a net loss in producer surplus for natural gas producers (Hausman and Kellogg 2015) but a gain for oil producers, whose production has increased greatly with only a modest price decline.

liquefy and export natural gas to global markets has expanded too slowly to absorb the supply growth. Oil, in contrast, is economical to transport and is traded on a massive global market, which domestic oil production has influenced but not overwhelmed. As a result, oil accounts for the other 20 percent of the savings, most of which are transportation sector savings on fuel.

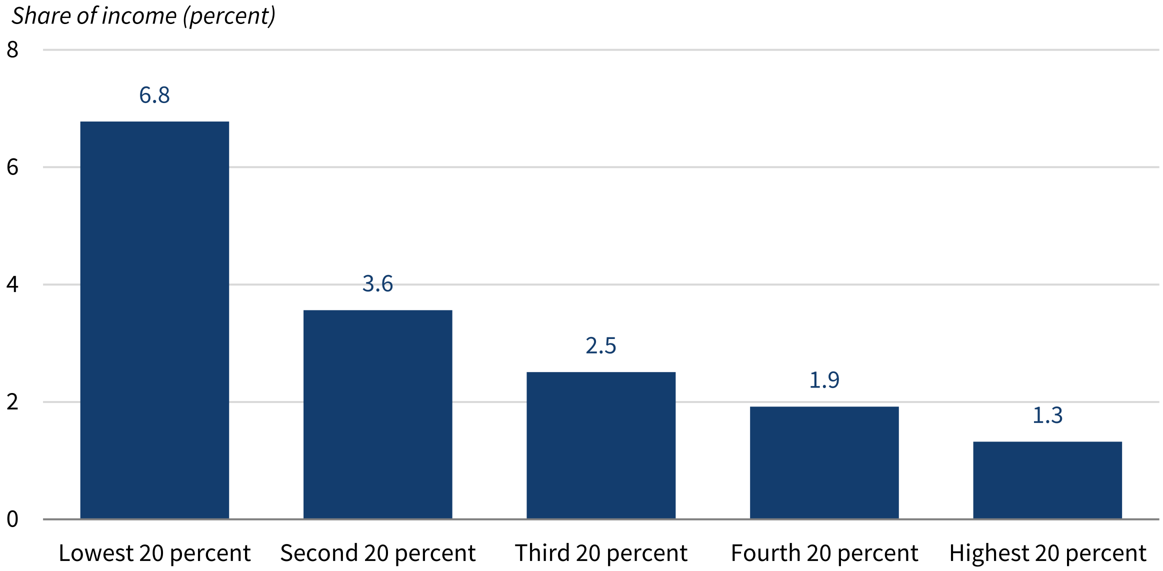
Figure 7. Shale-Driven Consumer Savings per Year by Source and Sector



Sources: Energy Information Administration (EIA); Kilian (2016); CEA calculations as described in the text and appendix.

Because lower-income households spend a larger share of their income on energy bills, the savings have greater relative importance to them. Energy savings represents 6.8 percent of income for the poorest fifth of households compared to 1.3 percent for the richest fifth of households (Figure 8). In other words, lower energy prices are like a progressive tax cut that helps the poorest households the most. The variation in savings stems heavily from differences in spending on electricity: according to the 2018 Consumer Expenditure Survey, the bottom 20 percent of households account for 8.6 percent of expenditures in general but 14.1 percent of electricity expenditures.

Figure 8. Consumer Savings as a Share of Income by Household Income Quintile

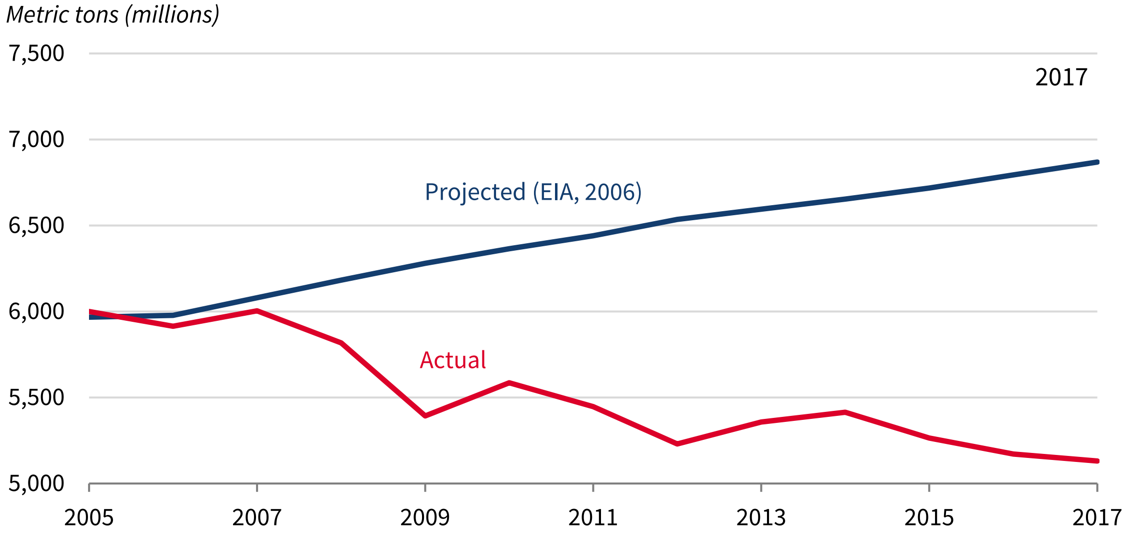


Sources: Bureau of Labor Statistics; CEA calculations as described in the appendix.
Note: Values represent CEA's estimates of consumer savings as a share of pre-tax income in 2018.

Environmental Benefits

In addition to saving the average family of four $2,500, the shale revolution has brought several environmental benefits. The shift to generating more electricity from natural gas and renewable sources reduced energy-related carbon dioxide emissions at the national level not predicted prior to these innovations. In its 2006 Annual Energy Outlook, the Energy Information Administration projected a 15 percent *increase* in carbon dioxide emissions from 2005 to 2017 (Figure 9). Actual emissions *decreased* by about 14 percent.

Figure 9. Actual vs. Projected Carbon Dioxide Emissions, 2005–17



Source: Energy Information Administration (EIA).
Note: Carbon dioxide emissions represent total emissions from the consumption of energy as reported by the EIA. Projections are from the EIA 2006 Annual Energy Outlook (AEO).

Actual energy-related carbon emissions for 2017 were 25 percent lower than projected in 2006. Some of the decline is because projections assumed greater GDP growth and therefore greater electricity demand than what actually occurred, in part because of the Great Recession and slow recovery. An important part of the decline, however, stems from lower natural gas prices reducing reliance on electricity from coal. Over the period, the percentage of generation from coal-fired plants fell from 50 percent to 30 percent while the share from natural gas increased from 19 percent to 32 percent.

Low natural gas prices also aided growth in the generation of wind power, which expanded from less than one percent of generation to 6 percent. Although Federal and State policies such as renewable portfolio standards and tax credits contributed to the increase in wind power generation, Fell and Kaffine (2018) document the important role of lower natural gas prices in spurring greater market penetration by wind generation. The complementarity stems from the ability of natural gas generators to quickly ramp up or slow down in response to the intermittent wind generation from gusts or lulls in wind.

We estimate that from 2005 to 2017, the shale revolution lowered annual energy-related emissions by 527 million metric tons, a 9 percent decline over the 2005 level (Figure 10).[7] For the estimate, we assume that coal emissions in the electricity sector would have otherwise

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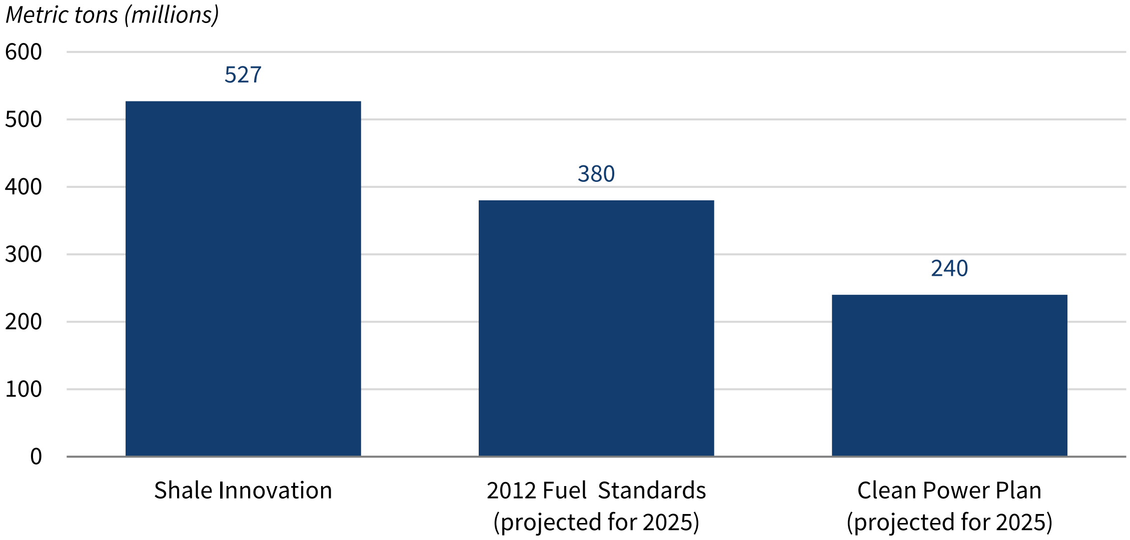
[7] We focus on domestic emission effects from shale gas. Effects on global emissions are difficult to quantify and are outside the scope of the paper, though others have studied them (Abrahams et al. 2015; Roman-White et al. 2019).

remained constant and calculate the observed decline in coal emissions, which is 776 million metric tons. We assume that 92 percent of the decline is from shale-driven decreases in natural gas prices. This percentage is from Coglianese, Gerarden, and Stock (2019) who estimate the share of the decline in coal use attributable to the decline in the price of natural gas relative to the price of coal apart from other factors such as environmental regulations, which accounted for another 6 percent of the decline.[8] Lastly, we subtract the increase in emissions from greater use of natural gas in electricity generation (527 million metric tons = 776 x 0.92 - 187).

The shale-driven reduction in emissions is larger than what the Environmental Protection Agency projected its 2012 Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards would achieve in 2025 (380 million metric tons) following a considerable increase in stringency. The shale reduction is also more than double what the EPA projected that the now-rescinded Clean Power Plan would achieve by 2025 (240 million metric tons).

Figure 10. Annual Greenhouse Gas Emission Reductions from Shale Innovation and Major Environmental Policies



Sources: Environmental Protection Agency; Stock (2017); CEA calculations.
Note: The Fuel Standards refer to the 2012 Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards, which applied to the 2017-2025 years.

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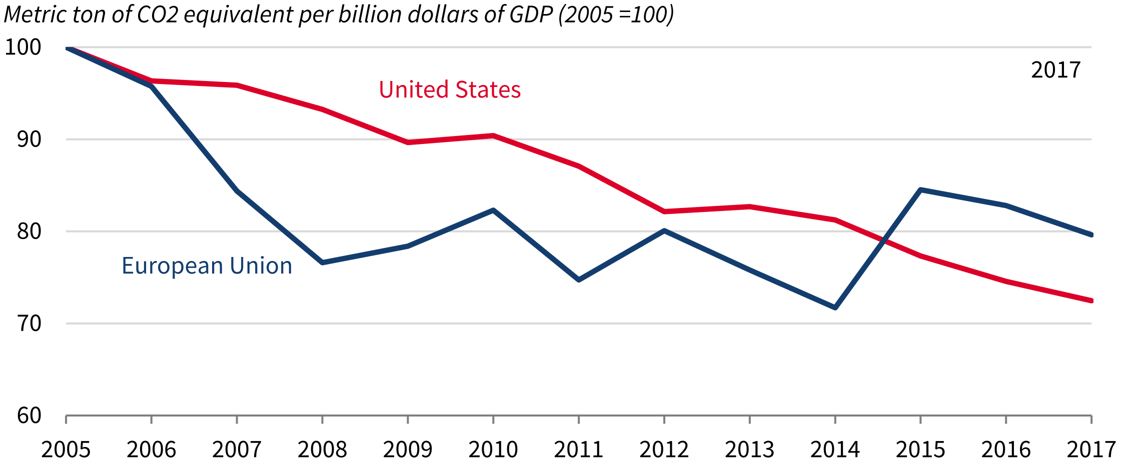
[8] Note that the decline in coal use and coal emissions is linked to the decline in the price of natural gas relative to the price of coal, not the number of coal plants that are replaced with natural gas plants. Natural gas-driven changes in electricity prices have caused coal plants to close and the retired generation capacity replaced with a mix of natural gas plants and renewable sources. Also, we note that Coglianese, Gerarden, and Stock (2018) look explicitly at coal production, not consumption, but the two are similar. Over most of their study period, more than 90 percent of production was consumed domestically.

The shale-driven decline in emissions allowed the United States to have a greater rate of decline in total GHG emissions than the European Union, holding constant the size of the two economies (Figure 11). From 2005 to the present, the European Union has developed and expanded an increasingly stringent cap and trade system for GHG emissions across its member countries. The system helped the European Union achieve a 20 percent decline in GDP-adjusted emissions from 2005 to 2017, though it raised electricity prices for consumers (Martin, Muuls, and Wagner 2016). Over the same period, emissions fell at a higher rate (28 percent decline) in the United States, which did not implement a cap and trade system.

Figure 11. U.S. vs. EU GDP-Adjusted Greenhouse Gas Emissions, 2005–17



Sources: Environmental Protection Agency; Bureau of Economic Analysis; European Environment Agency; Statistical Office of the European Communities; CEA calculations.

Note: Values are total greenhouse gas (GHG) emissions per billion 2017 U.S. dollars of each respective region's GDP. Values are normalized such that 2005 is equal to 100.

If policy makers had averted the shale revolution through a ban on hydraulic fracturing or other integral components to shale development, energy sector GHG emissions would most likely be higher today. Absent low natural gas prices, renewable electricity sources are unlikely to have enabled similar emissions reductions. A megawatt hour of coal-fired electricity generates about one ton of GHG emissions. Achieving the 527 million metric ton decline in GHG emissions is roughly equivalent to reducing coal-fired electricity generation by about 527 million megawatt hours and replacing it with renewable power generation. This amounts to a 154 percent increase in wind and solar generation above their 2018 level, an increase that is not projected to happen until 2046.[9]

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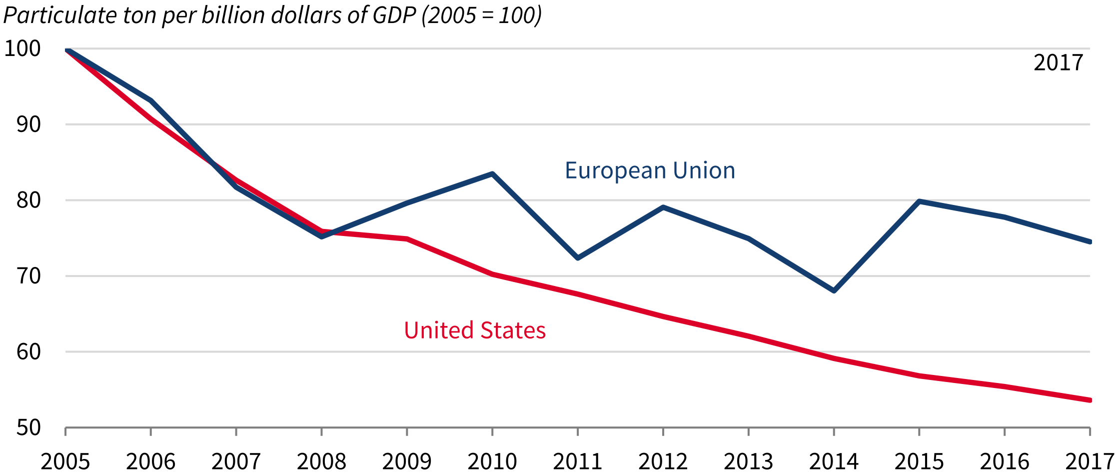
[9] The year of 2046 is estimated using the Energy Information Administration's (EIA) 2019 Annual Energy Outlook (AEO) forecast of wind and solar generation in the electric power sector through 2050 (EIA 2019c).

During the shale era, the percentage decline in coal-fired generation has roughly equaled the percentage decline in the wholesale price of electricity, suggesting that prices would need to fall 26 percent below their pre-shale level to reduce coal generation by 527 million megawatt hours (26 percent). The decline would leave wholesale electricity prices 32 percent above their 2018 level. A 32 percent higher price is unlikely to have supported a 154 percent increase in wind and solar generation over their 2018 level (and an even larger percent increase over their pre-shale level). It implies an elasticity of supply close to 5, roughly twice as large as the empirical estimate by Johnson (2014).

Shale-driven declines in emissions have been large as well as economical. Many policies seek to reduce emissions. Most of them, however, impose a cost on the economy. Gillingham and Stock (2018) summarize research on the cost of reducing a ton of carbon emissions by various methods. They report that renewable fuel subsidies cost $100 per ton of carbon abated, Renewable Portfolio Standards cost up to $190 per ton, and vehicle fuel economy standards cost up to $310 per ton. By comparison, shale innovation brings emissions savings without requiring greater public spending (e.g. subsidies) or costly regulations or mandates.

Lower natural gas prices have also affected emissions of particulates such as soot, which can affect heart and lung health, especially for those with asthma or heart or lung disease. As with GHG emissions, particulate emissions have declined faster in the United States than in the European Union over the 2005 to 2017 period (Figure 12). The difference in the rate of reduction is considerable, with U.S. particulate emissions per dollar of GDP declining by 57 percent and EU emissions declining by 41 percent. The decline has brought health benefits. Assuming that even low-levels of particulate exposure have health costs, Johnsen, LaRiviere, and Wolff (2019) estimate that as of 2013 the shale-driven decline in particulate and related emissions has $17 billion in annual health benefits.

Figure 12. U.S. vs. EU GDP Adjusted Particulate Emissions, 2005–17



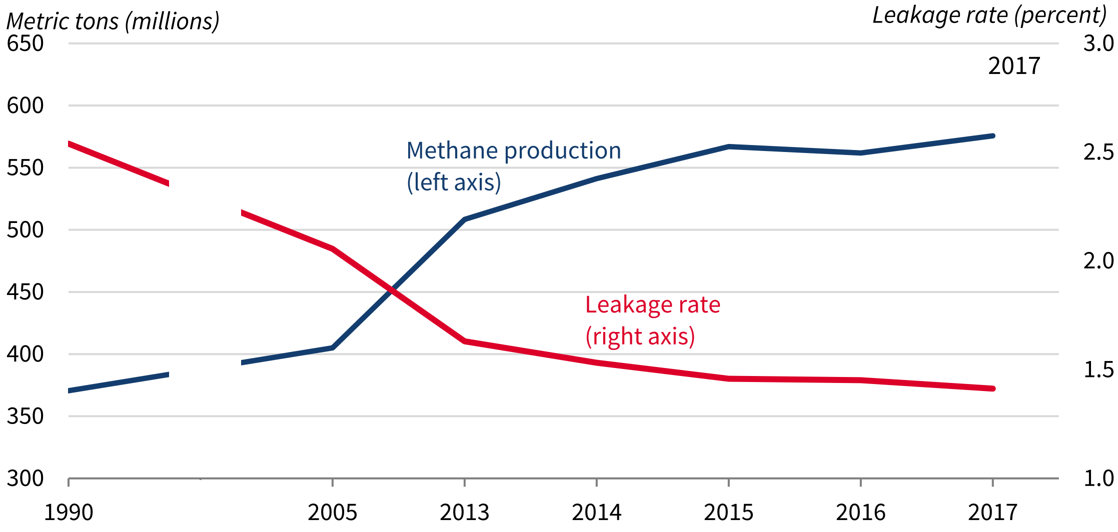
Sources: Environmental Protection Agency; Bureau of Economic Analysis; European Environment Agency; Statistical Office of the European Communities; CEA calculations.

Note: Values are total particulate matter emissions that are 2.5 microns or less in size per billion 2017 U.S. dollars of each respective region's GDP. Values are normalized such that 2005 is equal to 100. U.S. emissions exclude miscellaneous sources.

Box 1. Innovation in Pipeline Leak Detection

Pipelines are one of the most effective methods of transporting oil and gas, but they require monitoring and maintenance. Traditionally, monitoring has required that people travel along pipelines by foot, automobile, plane, or ATV. Innovation in technologies such as drones and advanced acoustics has allowed the industry to prevent leaks and more quickly find and stop them when they occur. For example, a Shell pilot drone program illustrates how well-equipped drones can identify pipeline corrosion, abnormal heat signatures, and any effects on wildlife. This helps the company identify leaks but also areas where preventive maintenance is most needed. With improvements to technology for monitoring pipeline leaks and other improvements across the supply chain, the leak rate for natural gas and petroleum systems fell 31 percent from 2005 to 2017 (figure i).

Figure i. Methane Production and Leakage Rates, 1990–2017



Source: Environmental Protection Agency; Energy Information Administration; CEA Calculations.
Note: Leakage rate calculated assuming wellhead gas is around 85% methane by volume and assuming methane density is 0.0447 pounds per cubic foot. Break in lines represents a break in data availability between 1990 and 2005.

Box 2. Shale Development and Local Communities

Many academic studies have explored the effects of shale oil and gas development on nearby communities. Two studies estimate measures of local net benefits across all major shale regions and reach a similar conclusion: local wage and income effects from development exceed increases in living costs or deterioration in local amenities (Bartik et al. 2019; Jacobsen 2019). Jacobsen (2019) finds that wages across all occupations increased in response to growth in drilling, regardless of whether they had direct links to the oil and gas industry, and were larger than the increase in housing rents. Similarly, Bartik et al. (2019) estimate that shale development generated $2,500 in net benefits to households in surrounding communities.

It is also evident that local effects can vary greatly, which is illustrated in the diverse effects of development on housing values. Housing values reflect an area's standard of living, including earnings opportunities and amenities such as good roads. Shale development affects both, creating jobs but also truck traffic and the associated disamenities (Litovitz et al. 2013; Graham et al. 2015). In addition, development can pose risk to groundwater and health and improper disposal of wastewater can induce earthquakes (Darrah et al 2014; Keranen et al. 2014; Wrenn, Klaiber, and Jaenicke 2016; Hill and Ma 2017; Currie, Greenstone, and Meckel 2017). Development has had large, positive effects on average housing values over time in many places (Boslett, Guilfoos, and Lang 2016; Weber, Burnett, and Xiarchos 2016; Bartik et al. 2019; Jacobsen 2019). Drilling itself, however, has depressed property values, at least temporarily, for groundwater-dependent homes in Pennsylvania or properties without mineral rights in Colorado (Muehlenbachs, Spiller, and Timmins 2015; Boslett, Guilfoos, and Lang 2016). Welfare effects can also vary across households in shale areas based on the value that households place on greater earning opportunities relative to disamenities such as noise or congestion.

The nuisances and risks that can come with drilling and fracturing wells highlight the value of prudent State and local policies that match local realities, safeguard the environment and human health, and allow private landowners to contract with energy firms to bring valuable energy resources to market. Almost all major producing States have revised oil and gas laws to address hydraulic fracturing and shale development more generally. North Dakota, for example, adopted rules limiting the flaring of natural gas in 2014, a practice that is especially common in the State because oil producers there have limited infrastructure to deliver to market the natural gas that accompanies oil production. Similarly, as shale development grew in Pennsylvania, the State adopted a policy that effectively ended treatment of fracking wastewater at publically owned treatment plants, which were shown to be insufficiently equipped to properly treat the water.

The Value of Pro-Innovation Energy Policy

Allowing Innovation to Flourish

Government deregulation of natural gas markets, including the 1978 Natural Gas Policy Act, the Federal Energy Regulatory Commission's 1985 Open Access Order, and the 1989 Natural Gas Wellhead Decontrol Act, helped encouraged the innovation that brought the shale revolution. In the same vein, the Trump Administration has sought to identify and remove regulations that unduly stifle energy development. This is seen by the Presidential Executive Order on Promoting Energy Independence and Economic Growth and the Executive Order on Promoting Energy Infrastructure and Economic Growth. It is also seen in actions such as the permitting of the Keystone XL Pipeline and the approval of a record amount of Liquefied Natural Gas export capacity to non-Free Trade Agreement countries.

The laboratory of State policy experiments provides examples of contrasting policy approaches and their effects. State governments have the primary responsibility to regulate oil and gas development on non-Federal lands, specifying where wells can be drilled, how they must be drilled and monitored, and how they are to be reclaimed at the end of their useful life. Subject to such regulations, most States allow shale development. Maryland, Vermont, and New York, however, have banned hydraulic fracturing, a practice integral to shale development. Of the three States, the New York ban is most consequential because the Marcellus Shale formation, which is the most prolific shale gas formation in the United States, extends into much of Southern New York. Since New York's de facto 2008 moratorium on fracking, which morphed into a ban in 2014, energy firms have drilled more than 2,500 wells in Pennsylvania counties adjacent to the New York border.

The difference in energy-related outcomes in the two States is stark. Development of the Marcellus and Utica Shale in Pennsylvania caused natural gas production to increase ten-fold from 2010 to 2017. Over the same period, New York's production fell by nearly 70 percent. Pennsylvania leads the country in net exports of electricity to other States and produces more than twice the amount of energy it consumes. New York, in contrast, has grown more dependent on electricity generated elsewhere, and in 2017, the State consumed four times as much energy as it produced.

Despite the growth in energy production in Pennsylvania, total energy-related GHG emissions fell 15 percent from 2010 to 2016, the most recent year of data, twice as much as in New York (7 percent). The greater decline in Pennsylvania stems from larger reductions in the electric power sector.

Box 3. Economic Effects Linked to Drilling and Production

Although this report focuses on the shale revolution's effect on prices and consumers, growth in drilling and production has also brought employment, income, and public revenues to producing regions and beyond. Relative to New York's border counties, which have not had shale development, Komarek (2016) found that counties in the Marcellus region that were developed had a 6.6 percent increase in earnings. Across the United States, Feyrer, Mansur, and Sacerdote (2017) estimate that new extraction increased aggregate employment by as much as 640,000 jobs. In addition to creating wage-earning opportunities, expanded drilling in places like North Dakota and Pennsylvania has also brought large payments to landowners holding rights to subsurface resources. Energy firms typically compensate resource owners by paying them a share of the value of production from their land. In 2014, production from major shale formations generated nearly $40 billion in payments to resource owners (Brown, Fitzgerald, and Weber 2016).

Drilling and production can also generate revenue for some State and local governments and local school districts. Between 2004 and 2013, State revenues from taxes on oil and gas production in the Lower 48 States nearly doubled, reaching $10.3 billion in real terms (Weber, Wang, and Chomas 2016). At the local level, increases in revenues have largely outweighed costs for local governments in most producing States (Newell and Raimi 2018). In certain States, such as Texas, oil and gas wells are also taxed as property and can therefore provide revenues to local school districts. For example, shale development in Texas' oil formations increased the property tax base by over a million dollars per student in the average shale district, leading to 20 percent more spending per student (Marchand and Weber 2019).

The Value of Energy Infrastructure

Pipelines, electric transmission lines, and related energy infrastructure allow energy resources to flow from resource-rich places to resource-scare places. The growth in oil and gas supply documented previously increases demand for pipelines. For example, with a dramatic rise in production over the last decade, Pennsylvania has switched from being a major importer of natural gas to being a major exporter. Acquiring regulatory approval and building the necessary pipelines has taken time, progressing to completion in some places but not others.

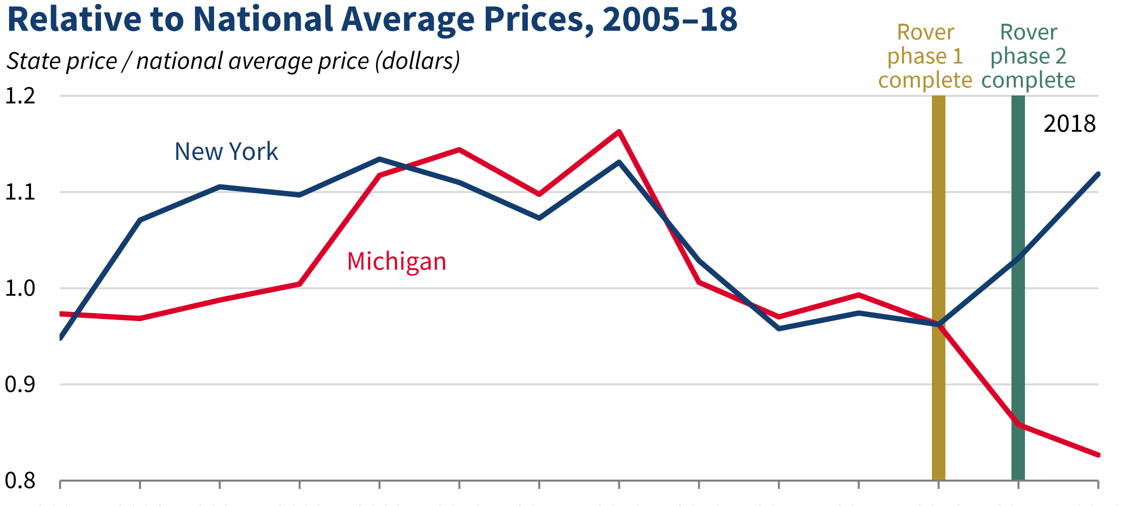
In 2017 and 2018, private firms finished two major pipeline projects, the Rover and Nexus pipelines, to take Appalachian gas into Michigan and beyond, with the projects adding nearly 1,000 miles of pipeline and 3.2 billion cubic feet of gas per day of capacity. The first phase of the Rover pipeline finished in August of 2017 and ran from Southeastern Ohio (near the Pennsylvania border) to Northeastern Ohio (near the Michigan border). The second phase finished in May of 2018 and extended the pipeline through Michigan and into Canada. The Nexus pipeline was also completed in 2018 and follows a similar route, eventually connecting into existing pipelines near Detroit.

No new interstate pipelines were built from Pennsylvania into New York (and therefore into New England) over the same time. Total expansions or extensions of existing pipelines that transit New York totaled 21 miles in length and 0.46 billion cubic feet per day in additional capacity. The 125-mile Constitution Pipeline, which would take Pennsylvania gas to New York and beyond has been repeatedly delayed since the project's inception in 2012, with a major source of delay being the refusal of the New York Department of Environmental Conservation to grant a necessary certification.

Natural gas price differences across States and over time illustrate the implications of new investments in pipelines. As natural gas production grew in Pennsylvania, Ohio, and West Virginia, citygate prices in Michigan fell relative to the national average price, plausibly reflecting the benefit of being closer to a place of burgeoning supply growth. (The citygate price measures local wholesale natural gas prices). From 2016 to 2018, during which two main pipeline projects were completed, the Michigan price relative to the national average price fell 14 percent. The New York price went the opposite direction, increasing 16 percent, potentially reflecting the interaction between high demand (from an above-average number of cooling-degree days in 2018) and pipeline constraints (Figure 13).

Figure 13. Citygate Natural Gas Prices in Michigan and New York Relative to National Average Prices, 2005–18

State price / national average price (dollars)



Sources: Energy Information Administration; CEA calculations.

Note: The Rover Pipeline phase 1 was completed in August 2017 and phase 2 was completed in May 2018. Vertical bars represent the beginning of the year in which the pipeline was completed, given annual data.

The 14 percent decline in the Michigan citygate price relative to the national price provides a credible estimate of the price effect of expanded pipeline capacity. It is similar to estimates of the effect of major capacity expansions (Oliver, Mason, and Finnoff 2014) or the price premium associated with insufficient capacity (Avalos, Fitzgerald, and Rucker, 2016).

A 14 percent decline in the New York and New England citygate price would save consumers in the region an estimated $2.0 billion annually, or $233 for a family of four. Some of the savings would be from residential, commercial, and industrial consumers paying less for the natural gas that they consume, but the bulk of savings would be from lower electricity prices. New York and most of New England have deregulated electricity markets where electricity generating firms sell into competitive markets. Linn, Muehlenbachs, and Wang (2014) find that for New York and New England, a 1 percent decrease in the price of natural gas lowers the price of electricity by 0.8 percent. Applying this gas-driven decline in wholesale prices to the region's consumption of electricity in 2018 provides $1.2 billion of the total $2.0 billion in savings.

It is also worth noting that pipelines are not the only means of transporting natural gas domestically. The Pipeline and Hazardous Materials Safety Administration is considering a permit request to transport liquefied natural gas by rail. In addition, greater waterborne trade in liquefied natural gas (LNG) could occur between U.S. ports if supported by policy. Currently, policy-related restrictions on transporting LNG by tanker between U.S. ports leaves New England dependent on LNG from foreign sources during times of peak demand.

Conclusion

The shale revolution provides a striking example of the potential of private sector energy innovation and the resulting implications for consumers and the environment. In less than a decade, productivity in oil and gas extraction has increased several fold. As a result, production costs have fallen, making energy goods and services more affordable for consumers, especially lower-income households. By several measures, the shale revolution has led to greater environmental progress in the United States than in the European Union, which exercises more government control and has more stringent emissions policies.

The Trump Administration's deregulatory policies aim to support private sector innovation and initiative by reducing excessively prescriptive government regulation. In doing so, the Administration seeks to further unleash the country's abundant human and energy resources. This policy stance is consistent with the approach taken by most States, which have allowed shale production to flourish as long as companies meet updated State policies that limit risks to human health and the environment. However, some States have taken a more commandand-control approach, which has had predictable effects. In particular, New York has taken an alternative, unsafe-at-any-speed approach to shale development. As it has done so, its natural gas production has fallen, its imports of electricity have increased, and its rate of GHG emissions reduction has been less than that of the neighboring State of Pennsylvania.

State and Federal policy questions related to shale will persist in debates about environmental and energy policy. The shale revolution will continue to influence energy prices. Price busts may push shale-focused firms into bankruptcy for a season, but the private sector has shown that large amounts of oil and gas can be extracted from shale and similar formations at reduced prices. The innovation introduces an inherent opportunity cost—in large part the consumer savings and environmental gains documented in this report—of policies that would severely constrain development. The Trump Administration’s deregulatory energy agenda, in contrast, seeks to overcome government barriers to private sector innovation that both lower the cost of energy and benefit the environment.

Appendix

Estimating Electricity Power Sector Savings from Lower Natural Gas Prices

We first estimate savings to the electric power sector in the same manner as Hausman and Kellogg (2015); call this S^{HK}. Their approach assumes that each dollar saved because of cheaper natural gas translates into a dollar saved for electricity consumers. This is a reasonable approach for the share of the power sector with cost-of-service regulation, in which case regulators would only reduce compensation to natural-gas-fired generators, not to other generators, and only by as much as such generators had cost reductions.

For the share of the sector without cost-of-service regulation, however, we translate the lower natural gas prices into lower wholesale electricity prices following Linn, Muehlenbachs, and Wang (2014). The price-setting effect of natural-gas-fired electricity generators magnifies the effect of lower natural gas prices because the gas-driven decline in wholesale electricity prices applies to all electricity consumed in deregulated markets, not just the electricity generated by natural gas. We then assume that wholesale market savings pass through to retail savings dollar for dollar, which is consistent with Borenstein and Bushnell (2015) who find high rates of pass through in deregulated markets.

One-third of electricity generated in the United States in 2018 was sold through competitive wholesale markets in States without cost-of-service regulation of generators.[10] Based on this share, we estimate total electric power savings to be the sum of the savings in regulated markets (= 0.66 x S^{HK}) and the savings from unregulated markets (=0.33 x $S^{Wholesale}$).

The Distribution of Savings Across Sectors and Household Income Groups

The approach to estimating natural gas savings, which involves sector-specific consumption amounts and demand curves, permits calculating savings for the residential, commercial, and industrial sectors, which we collapse into the non-electric sector, and the electric sector. For oil, we allocate savings to the transportation sector based on its share of total petroleum consumption in the United States (70 percent) as reported by the Energy Information Administration for 2018.

Regarding the pass-through of energy savings to household income groups, we first allocate residential natural gas and residential electricity savings based on each income group's share of spending on natural gas and electricity as reported in the 2018 Consumer Expenditure

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[10] The Energy Information Administration provided CEA with analysis of data from EIA form 923, which collects detailed information from the electric power sector. The analysis showed that in 2018, 33 percent of electric power supply occurred in Regional Transmission Organizations in unregulated States.

Survey of the Bureau of Labor Statistics. We then estimate the oil-related transportation sector savings associated with direct household consumption by multiplying the total oil savings by the share of transportation sector energy use accounted for by light-duty vehicles such as cars and sport utility vehicles. These direct household savings are then distributed to household income groups based on each groups' spending on "Gasoline, other fuels, and motor oil" as reported in the 2018 Consumer Expenditure Survey.

Lastly, we allocate the natural gas, electricity, and oil-related savings that initially occur in the commercial and industrial sectors. We assume that the savings are eventually passed through to households in the form of lower product prices, with savings allocated to each household income group according to its share of total household expenditures as reported in the 2018 Consumer Expenditure Survey of the Bureau of Labor Statistics. This is a common approach in the literature on the incidence of carbon taxes, which increase energy prices (Mathur and Morris 2014). It also has empirical support in important product markets (e.g. Muehlegger and Sweeney 2017). The export of some of the industrial sectors' output to global markets would suggest that the approach overstates savings to U.S. consumers. The shale revolution, however, has also reduced global energy prices, which would lower the costs of foreign producers, some of whom serve the U.S. market. We assume that these competing effects offset each other.

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