

Putting Downward Pressure on Natural Gas Prices: The Impact of Renewable Energy and Energy Efficiency

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ABSTRACT

Increased deployment of renewable energy (RE) and energy efficiency (EE) is expected to reduce natural gas demand and in turn place downward pressure on gas prices. A number of recent modeling studies include an evaluation of this effect. Based on data compiled from those studies summarized in this paper, each 1% reduction in national natural gas demand appears likely to lead to a long-term average wellhead gas price reduction of 0.75% to 2.5%, with some studies predicting even more sizable reductions. Reductions in wellhead prices will reduce wholesale and retail electricity rates, and will also reduce residential, commercial, and industrial gas bills. We further find that many of these studies appear to represent the potential impact of RE and EE on natural gas prices within the bounds of current knowledge, but that current knowledge of how to estimate this effect is extremely limited. While more research is therefore needed, existing studies suggest that it is not unreasonable to expect that any increase in consumer electricity costs attributable to RE and/or EE deployment may be substantially offset by the corresponding reduction in delivered natural gas prices. This effect represents a wealth transfer (from natural gas producers to consumers) rather than a net gain in social welfare, and is therefore not a standard motivation for policy intervention on economic grounds. Reducing gas prices and thereby redistributing wealth may still be of importance in policy circles, however, and may be viewed in those circles as a positive ancillary effect of RE and EE deployment.

Introduction

Renewable energy (RE) and energy efficiency (EE) have historically been supported due to perceived economic, environmental, economic development, and national security benefits. More recently, price volatility in wholesale electricity and natural gas markets has increasingly led to discussions about the potential risk mitigation value of these resources. Deepening concerns about the ability of conventional North American gas production to keep up with demand have also resulted in a growing number of voices calling for resource diversification.

RE and EE offer a direct hedge against volatile and escalating gas prices by reducing the need to purchase variable-price natural gas-fired electricity generation, replacing that generation with fixed-price RE or EE resources. In addition to this *direct* contribution to price stability, by displacing marginal gas-fired generation, RE and EE can reduce demand for natural gas and *indirectly* place downward pressure on gas prices.² Many recent modeling studies of increased RE and EE deployment have demonstrated that this “secondary” effect on natural gas prices

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² Improvements in natural gas conversion efficiency, and end-use natural gas efficiency measures, would also directly reduce gas demand, as would increases in coal or nuclear generation.

could be significant, with the consumer benefits from reduced gas prices in many cases more than offsetting any increase in electricity costs caused by RE/EE deployment.³ As a result, this effect is increasingly cited as justification for policies promoting EE and RE. Yet to date, little work has focused on reviewing the reasonableness of this effect as portrayed in various studies, and benchmarking that output against economic theory. This paper begins to fill that void.

We first review economic theory to better understand the economics underlying the price suppression effect. We then review many of the modeling studies conducted over the past five years that have measured this effect, illustrating the potential impacts of RE and EE deployment on consumer electricity and gas bills, and calculating the inverse price elasticity of gas supply implied by the modeling output. We compare the resulting range of inverse price elasticities with each other (to test for model consistency across time and across models), as well as to empirical estimates from the economics literature (to test for model consistency with the real world). We end the paper with a summary of our findings.

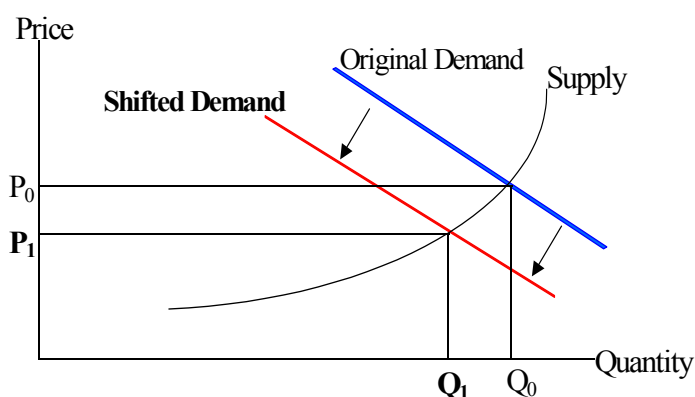
Natural Gas Supply and Demand: A Review of Economic Theory

Supply and Demand Curves

Whether today's inflated natural gas prices represent merely a short-term imbalance between supply and demand, or instead a longer-term effect that reflects the true long-term marginal cost of production, is unclear (see, e.g., EMF 2003; Henning, Sloan & de Leon 2003; NPC 2003). In either case, economic theory predicts that a reduction in natural gas demand, whether caused by enhanced electric or natural gas efficiency, or by increased deployment of RE, will generally lead to a subsequent reduction in the price of gas relative to the price that would have been expected under higher demand conditions. As shown in Figure 1, this price reduction ($P_0 \rightarrow P_1$) results from an inward shift in the aggregate demand curve for natural gas ($Q_0 \rightarrow Q_1$). Because gas consumers are "price takers" in a market whose price is determined by national supply and demand conditions (with some regional differentiation), the price reduction benefits consumers by reducing gas prices for electricity generators (assumed to be passed through, in part, in the form of lower electricity prices), and by reducing gas prices for direct use in the residential, commercial, industrial, and transportation sectors.

The magnitude of the price reduction will clearly depend on the amount of demand reduction: greater amounts of gas displacement will lead to greater drops in the price of the

Figure 1. The Effects of a Shift in Demand for Natural Gas



³ Note that any increase in costs associated with renewable energy or energy efficiency could be due to technology-forcing standards (e.g., a renewables portfolio standard or appliance energy efficiency standards), or to the imposition of a system-benefits charge used to support these clean energy technologies.

commodity.⁴ As long as gas prices remain within reasonable bounds, RE and EE are expected to largely displace gas generation; the higher gas price forecasts of recent years, however, suggest that RE and EE may increasingly displace coal over time, muting the impact on gas prices. As importantly, the shape of the gas supply curve – the relationship between the level of natural gas production and the price of supply – will also have a sizable impact on the magnitude of the price reduction. The shape of the supply curve for natural gas will, in turn, depend on whether one considers short-term or long-term effects. Economists generally assume upward, steeply sloping supply curves in the short term when supply constraints exist in the form of fixed inputs like labor, machinery, and well capacity. In this instance, gas producers are unable or unlikely to quickly and dramatically increase (decrease) supply in response to higher (or lower) gas prices.

In the long term, however, the supply curve will flatten because supply will have time to adjust to lower demand expectations, for example, by reducing exploration and drilling expenditures. Because natural gas is a non-renewable commodity, the long-term supply curve must eventually slope upward as exhaustion of the least expensive resources occurs. If the pace of technological innovation in exploration and extraction is rapid, however, the transition to more expensive reserves may be delayed and the long-term supply curve may remain relatively flat. The shape of the long-term supply curve is an empirical question, and is subject to great uncertainty and debate. Nonetheless, economists generally agree that, while both the short- and long-term supply curves are upward sloping, the long-term supply curve will generally be flatter than the short-term supply curve. This implies that the impact of increased RE and EE deployment on natural gas prices will be greater in the short term than in the long term. We return to these issues later, when reviewing modeling output.

In this paper, we emphasize the long-term impacts of RE and EE investments, and hence focus our attention on the shape of the long-term supply curve. We do this for two principal reasons. First, RE and EE investments are typically long-term in nature, so the most enduring effects of these investments are likely to occur in the long term. Second, the model results presented in this paper often do not clearly distinguish between short-term and long-term effects, and most models appear better suited to long-term analysis. We also focus on the *national* impacts of increased RE and EE deployment; future work will review the impacts of *regionally* focused RE and EE investment.

Measuring the Inverse Price Elasticity of Supply

To measure the degree to which shifts in gas demand affect the price of natural gas, it is convenient to use elasticity measures. The *price elasticity of natural gas supply* is a measure of the responsiveness of natural gas supply to the price of the commodity, and is calculated by dividing the percentage change in quantity supplied by the percentage change in price:

$$E = (\% \Delta Q) / (\% \Delta P), \text{ where } Q \text{ and } P \text{ denote quantity and price, respectively.}$$

⁴ One would not generally expect any particular threshold of demand reduction to be required to lower the price of gas. Instead, greater quantities of gas savings should simply result in higher levels of price reduction. The impact on prices, however, need not be linear over the full range of demand reductions, but will instead depend on the exact – yet unknown – shape of the supply curve in the region in which it intersects the demand curve.

In the case of induced shifts in the demand for natural gas, however, we are interested in understanding the change in price that will result from a given change in quantity, or the *inverse price elasticity of supply* (“inverse elasticity”):

$$E^{-1} = (\% \Delta P) / (\% \Delta Q)$$

Given greater supply responsiveness over the long term than in the short term, the long-term supply curve should experience *lower* inverse price elasticities of supply than will the short-term supply curve.

Social Benefits, Consumer Benefits, and Wealth Transfers

We have made the case that increased deployment of RE and EE can and should lower the price of natural gas relative to a business-as-usual trajectory. The magnitude of the expected price reduction is an empirical question that we address in later sections of this paper. Before proceeding, however, it is important to address the nature of the “benefit” that is obtained with the price reduction, because mischaracterizations of this benefit are common, and may lead to unrealistic expectations and policy prescriptions.

In particular, according to economic theory, lower natural gas prices that result from an inward shift in the demand curve do not lead to a gain in net economic welfare, but rather to a shift of resources (i.e., a transfer payment) from natural gas producers to natural gas consumers. While natural gas producers see their profit margins decline (a loss of producer surplus), natural gas consumers benefit through lower natural gas bills (a gain of consumer surplus). The net effect on aggregate social welfare (producer plus consumer surplus) is zero assuming a perfectly competitive and well-functioning aggregate economy.

This effect is shown graphically in Figures 2 and 3. Figure 2 shows consumer and

Figure 2. Consumer and Producer Surplus

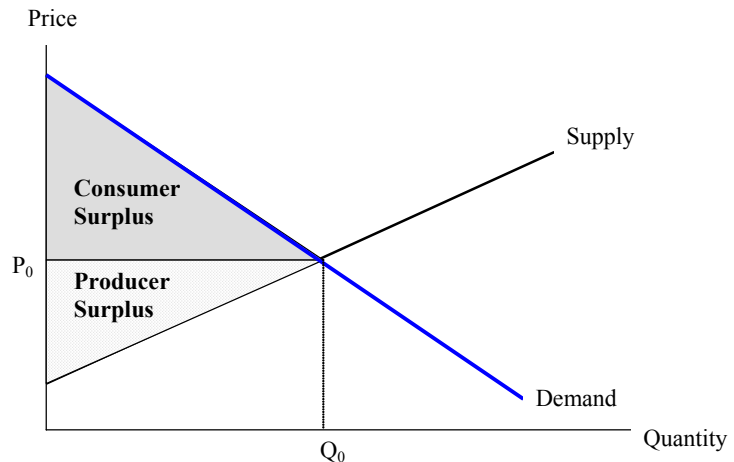
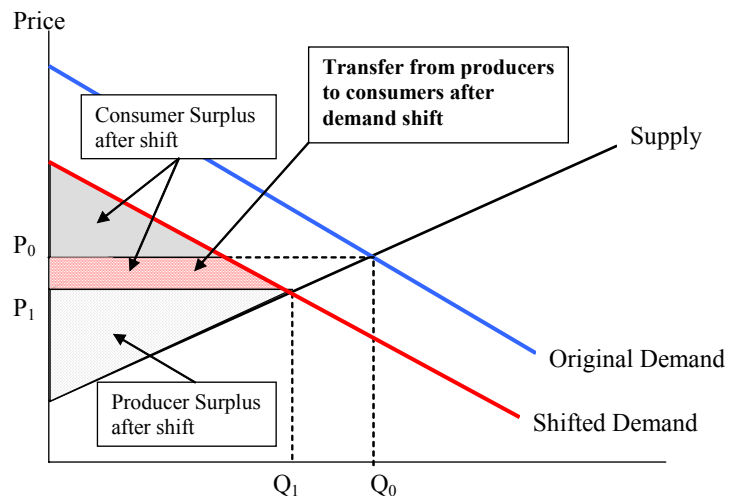


Figure 3. The Effect of a Demand Shift



producer surplus before the demand shift, while Figure 3 shows the impact of the demand shift on consumer and producer surplus. After the shift, the market price and quantity of natural gas fall to P_1 and Q_1 , and consumer surplus now also includes the cross-hatch area in Figure 3 that was previously producer surplus. This area represents the price reduction benefit that consumers gain, and represents a redistribution of wealth from producers to consumers.

Wealth transfers of this type are not generally considered justification for policy intervention on economic grounds. Reducing gas prices and thereby redistributing wealth may still be of importance in policy circles, however, and may be viewed in those circles as a positive ancillary effect of RE and EE deployment; energy programs are frequently assessed using consumer impacts as a key evaluation metric. Furthermore, this effect may in fact provide a welfare gain if economy-wide macroeconomic adjustment costs are expected to be severe in the case of gas price spikes and escalation, or if the demand reduction is significant enough to mitigate the potential for market power in the gas market. Additionally, if consumers are located within the U.S., and producers are located outside of the U.S., the wealth redistribution would serve to increase aggregate U.S. welfare, an increasingly likely situation as the country becomes more reliant on imports of natural gas (especially liquefied natural gas). Finally, lower gas prices may help preserve U.S. manufacturing jobs, lead to displacement of more polluting energy sources, and reduce the cost of environmental regulatory compliance. We leave it to others to further debate the merits of considering this effect in policy evaluation.

A Review of Previous Studies

Previous studies of RE and EE policies have estimated the impact of increased clean energy deployment on natural gas prices. Many of these studies have exclusively evaluated a *renewables portfolio standard* (RPS) – a policy that requires electricity suppliers to source an increasing percentage of their supply from RE over time – while others have also looked at EE and environmental policies. These studies have focused on national as well as state-level policies, and have most typically used the National Energy Modeling System (NEMS), a model that is revised annually, and that is developed and operated by the DOE’s Energy Information Administration (EIA) to provide long-term (e.g., to 2020 or 2025) energy forecasts.

While the shape of the short-term natural gas supply curve is a transparent, exogenous input to NEMS, the model (as well as other energy models reviewed for this study) does not exogenously define a transparent long-term supply curve; instead, a variety of modeling assumptions are made which, when combined, implicitly define the supply curve. For this reason, in order to evaluate the long-term gas price effect of RE and EE by measuring the inverse price elasticity of supply, it is necessary to do so implicitly by reviewing modeling results.

For the purposes of this paper, we have sought to compile information on a subset of the relevant studies. These include: (1) five studies by the EIA focusing on national RPS policies, two of which model multiple RPS scenarios; (2) five studies of national RPS policies by the Union of Concerned Scientists (UCS), two of which model multiple RPS scenarios, and one of which also includes aggressive energy efficiency investments; (3) one study by the Tellus Institute that evaluates three different standards of a state-level RPS in Rhode Island (combined with the RPS policies in Massachusetts and Connecticut); and (4) an ACEEE study that explores the impact of national and regional RE and EE deployment on natural gas prices. The EIA, UCS, and Tellus studies were all conducted in NEMS (note that NEMS is revised annually, and that

these studies were therefore conducted with different versions of NEMS), while the ACEEE study used a gas market model from Energy and Environmental Analysis (EEA).

Table 1 presents a summary of some of the results of these studies.⁵ A majority of the studies predict that increased RE generation (and EE, if applicable) will modestly increase retail electricity prices on a national basis, though this is not always the case. Increased RE and EE also cause a reduction in gas consumption, ranging from less than 1% to nearly 30% depending on the study. Reduced gas consumption, in turn, suppresses gas prices, with price reductions ranging from virtually no change in the national average wellhead price to a 50% reduction in that price. As one might expect, the more significant reductions in gas consumption and prices are typically associated with those studies that evaluated aggressive RE/EE deployment.

Table 1. Summary of Results from Past RPS Studies

Author	RPS/EE	Increase in US RE Generation	Reduction in US Gas Consumption	Gas Wellhead Price Reduction	Retail Electric Price Increase
		<i>Billion kWh</i>	<i>Quads (%)</i>	<i>\$/MMBtu (%)</i>	<i>Cents/kWh (%)</i>
EIA (1998)	10%-2010 (US)	336	1.12 (3.4%)	0.34 (12.9%)	0.21 (3.6%)
EIA (1999)	7.5%-2020 (US)	186	0.41 (1.3%)	0.19 (6.6%)	0.10 (1.7%)
EIA (2001)	10%-2020 (US)	335	1.45 (4.0%)	0.27 (8.4%)	0.01 (0.2%)
EIA (2001)	20%-2020 (US)	800	3.89 (10.8%)	0.56 (17.4%)	0.27 (4.3%)
EIA (2002a)	10%-2020 (US)	256	0.72 (2.1%)	0.12 (3.7%)	0.09 (1.4%)
EIA (2002a)	20%-2020 (US)	372	1.32 (3.8%)	0.22 (6.7%)	0.19 (2.9%)
EIA (2003)	10%-2020 (US)	135	0.48 (1.4%)	0.00 (0.0%)	0.04 (0.6%)
UCS (2001)	20%-2020, & EE (US)	353	10.54 (29.7%)	1.58 (50.8%)	0.17 (2.8%)
UCS (2002a)	10%-2020 (US)	355	1.28 (3.6%)	0.32 (10.4%)	-0.18 (-2.9%)
UCS (2002a)	20%-2020 (US)	836	3.21 (9.0%)	0.55 (17.9%)	0.19 (3.0%)
UCS (2002b)	10%-2020 (US)	165	0.72 (2.1%)	0.05 (1.5%)	-0.07 (-1.1%)
UCS (2003)	10%-2020 (US)	185	0.10 (0.3%)	0.14 (3.2%)	-0.14 (-2.0%)
UCS (2004)	10%-2020 (US)	181	0.49 (1.6%)	0.12 (3.1%)	-0.12 (-1.8%)
UCS (2004)	20%-2020 (US)	653	1.80 (5.8%)	0.07 (1.87%)	0.09 (1.3%)
Tellus (2002)	10%-2020 (RI)	31	0.13 (0.4%)	0.00 (0.0%)	0.02 (0.1%)
Tellus (2002)	15%-2020 (RI)	89	0.23 (0.7%)	0.01 (0.4%)	-0.05 (-0.3%)
Tellus, (2002)	20%-2020 (RI)	98	0.28 (0.8%)	0.02 (0.8%)	-0.07 (-0.4%)
ACEEE (2003)	6.3%-2008, & EE (US)	NA	1.37 (5.4%)	0.74 (22.1%)	NA

Notes:

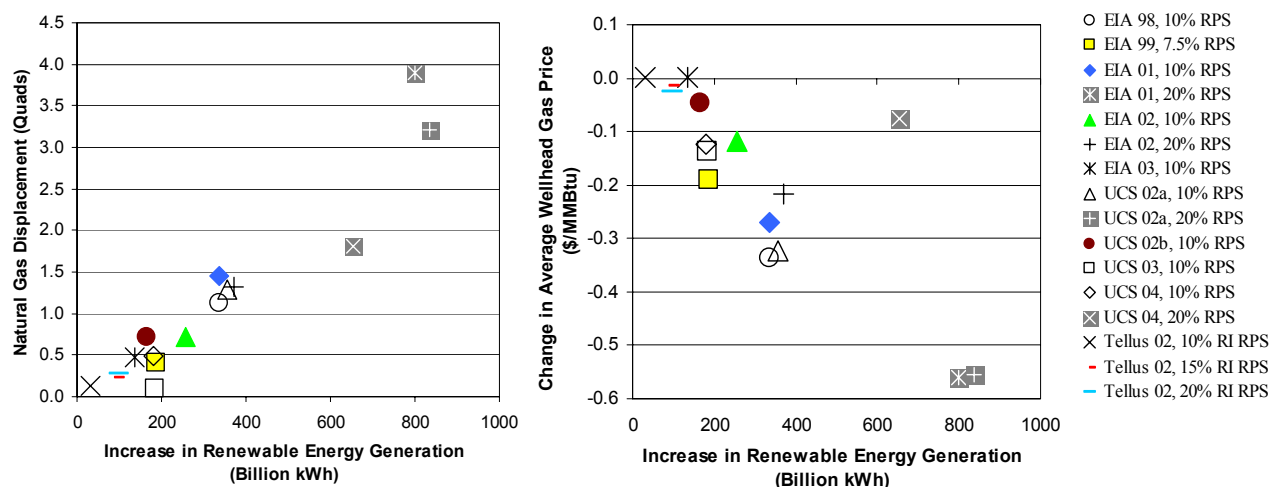
- The data for the ACEEE study are for 2008, the final year of the study's forecast. All other data are for 2020.
- All dollar figures are in constant 2000\$.
- The reference case in most studies reflects the EIA AEO, with some studies making adjustments based on more recent gas prices or altered renewable technology assumptions. The one exception is UCS (2003), in which the reference case reflects a substantially higher gas price environment than the relevant AEO reference case.
- The Tellus study models an RPS for RI, also including the impacts of the MA and CT RPS policies. All the figures shown in this table are for the predicted *national* level impacts of these regional policies.

Wellhead price reductions translate into reduced bills for natural gas consumers, and also moderate the expected RE-induced increase in electricity prices predicted by many of the studies by reducing the price of gas delivered to the electricity sector. Though not shown in Table 1,

⁵ Table 1 presents the projected impacts of increased RE and EE deployment in each study relative to some baseline. These baselines differ from study to study, which partially explains why, for example, a 10% RPS in two studies can lead to different impacts on renewable generation.

with some exceptions, the absolute reduction in electric and non-electric sector delivered natural gas prices largely mirrors the reduction in wellhead gas prices, suggesting that changes in wellhead prices largely flow through to delivered prices on an approximate one-for-one basis.

Focusing on just those studies that *exclude* EE deployment (i.e., all but ACEEE 2003, and UCS 2001),⁶ Figure 4 presents the impact of increased RE generation on the displacement of national gas consumption in 2020. Figure 5, meanwhile, shows the impact of increased RE on the national average wellhead price of natural gas.



These figures, along with Table 1, show clearly that increased RE and EE are predicted to reduce natural gas consumption and prices, while retail electricity prices are predicted to rise in at least some instances. The net predicted effect on consumer energy bills can be positive or negative, depending on the relative magnitude of the electricity and natural gas bill effects.

Again taking a subset of the studies, Figure 6 presents these offsetting effects.⁷ While variations exist across the different studies, the net present value of the cumulative (2003-2020) predicted increase in consumer electricity bills (if any) in the RPS cases compared to the reference case is often on the same order of magnitude as the net present value of the predicted decrease in consumer natural gas bills. From an aggregate *consumer* perspective, therefore, the net impact of these policies is typically predicted to be rather small, with nine of thirteen RPS analyses even showing net consumer savings (i.e., negative cumulative bill impacts).⁸

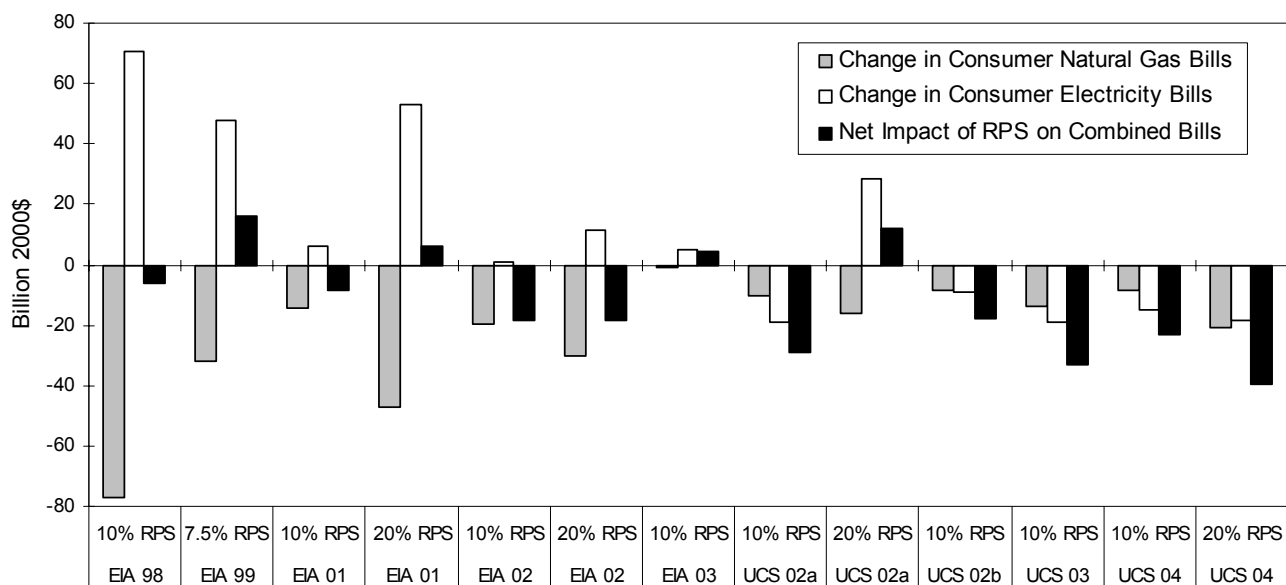
Though not shown explicitly in these tables and figures, also note that RE and EE are expected to lead to greater reductions in gas consumption in those studies that rely on lower gas price forecasts in the business-as-usual scenario. More recent studies that often rely on higher gas price forecasts (e.g., UCS 2003, 2004) generally find greater coal displacement (and less gas

⁶ We exclude the two studies that involve EE deployment here only to simplify the graphical results.

⁷ Figure 6 shows the energy bill impacts only for the national RPS studies for which these data were available (i.e., it excludes the Tellus analysis as well as the two studies in which EE investments were also modeled).

⁸ Note that in several of these studies, RPS cost caps are reached, ensuring that consumers pay a capped price for some number of *proxy* renewable energy credits (and leading to increased electricity prices) while not obtaining the benefits of increased RE generation on natural gas prices. Accordingly, if anything, Figure 6 underestimates the possible consumer benefits of a well-designed renewable energy program with less-binding cost caps.

displacement) over time as coal out-competes gas for new additions. In a high gas-price environment, this effect may mitigate the benefit of RE and EE in reducing those prices.



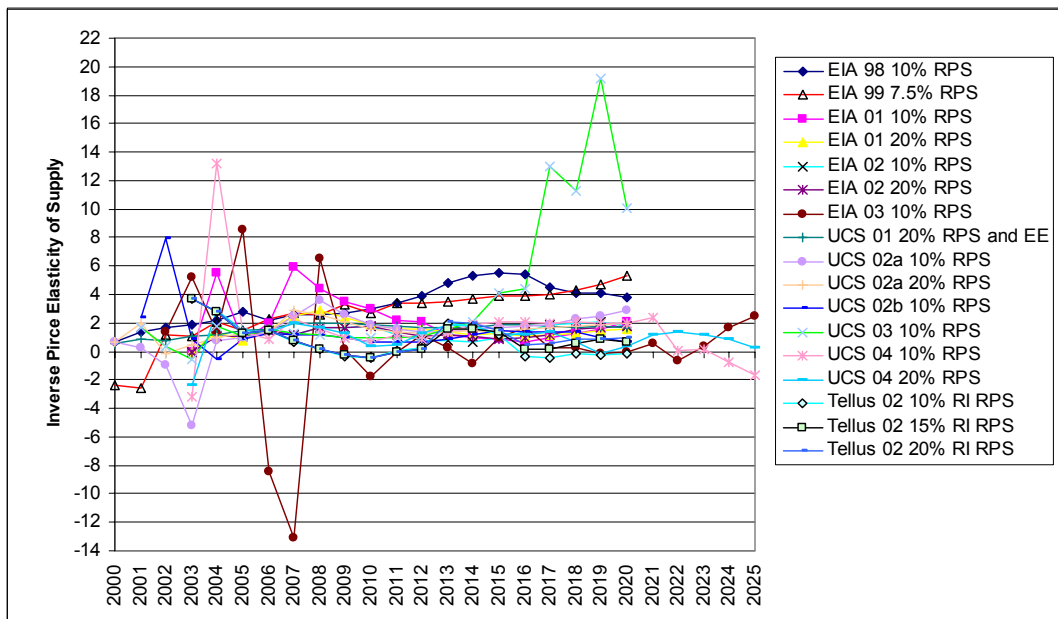
Summary of Implied Inverse Price Elasticities of Supply

Ignoring for now the different impacts of RE/EE on gas consumption across studies, to compare the natural gas price response to increased RE and EE deployment we can calculate the inverse price elasticity of supply implied by the results of each study. Doing so requires data on the predicted average national wellhead price of natural gas and total gas consumption in the United States, under both the business-as-usual baseline scenario as well as the policy scenario of increased RE and/or EE deployment.⁹ With the possible exception of the ACEEE study, the resulting inverse elasticities can be considered long-term elasticities.¹⁰

Figure 7 presents a comparative analysis of *long-term* implicit inverse elasticities across studies and years (excluding the ACEEE 2003 results, which are presented later). As shown, the implied inverse elasticity in each study exhibits a great deal of variation over the forecast period. Though some of the studies show a reasonable level of consistency in the inverse elasticity over time, others show large inter-annual swings. This is especially (though not always) true when the aggregate reduction in gas demand is small, leading to substantial “noise” in the results.

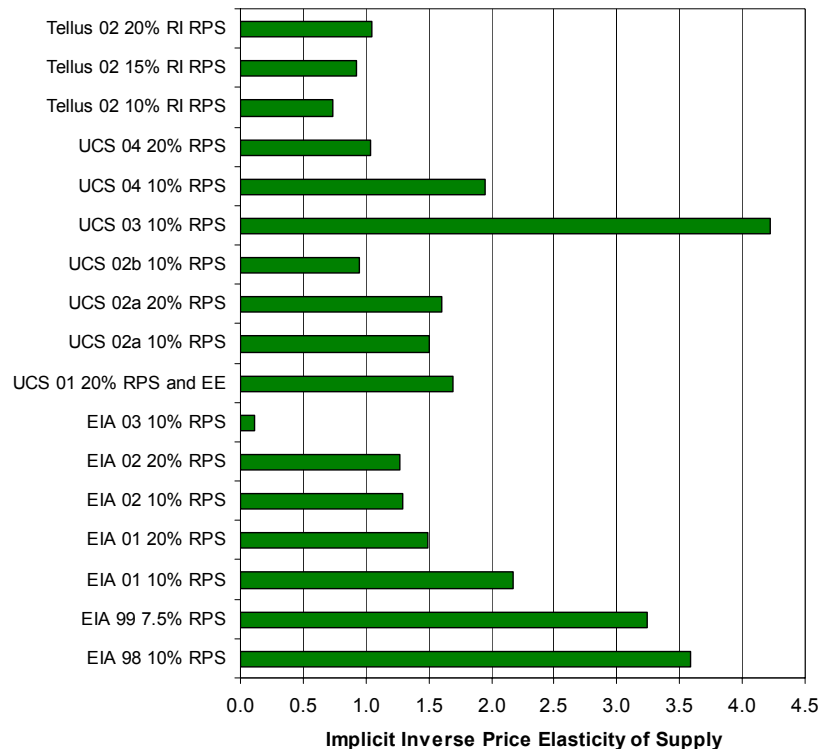
⁹ The inverse elasticity calculations presented here use U.S. price and quantity data, under the assumption that at present the market for natural gas is more regional than worldwide in nature (Henning, Sloan & de Leon 2003). Of course, the market for natural gas consumed in the U.S. is arguably a North American market, including Canada and Mexico, with LNG expected to play an increasing role in the future. Trade with Mexico is relatively small, however, and Canadian demand for gas pales when compared to U.S. demand. LNG, meanwhile, remains a modest contributor to total U.S. consumption.

¹⁰ It deserves note that our review of NEMS output in the national RPS studies shows that predicted natural gas prices in NEMS do not appear to be more sensitive to demand changes in the short-term than in the long-term. Because of this, one might question NEMS’ treatment of long-term and short-term natural gas supply elasticities.



Because relying on the implied inverse elasticity for any single year could be misleading, Figure 8 summarizes the average value of the implied inverse elasticities over an extended forecast period (2003-2020). Despite substantial inter-annual and inter-study variations, there is some consistency in the *average* long-term inverse elasticities, with twelve of seventeen analyses (all of which use NEMS) having elasticities that fall within the range of 0.7 to 2.0.¹¹

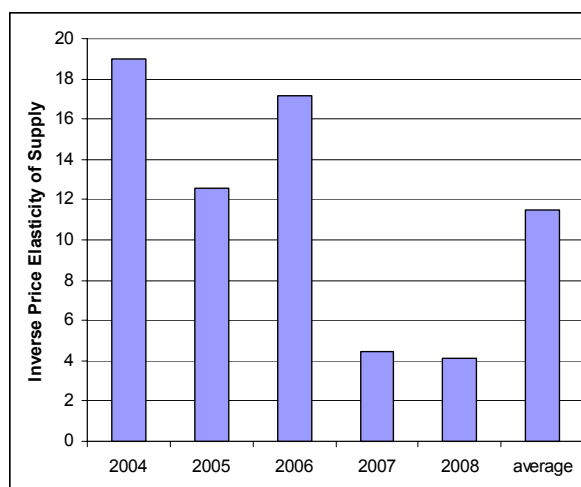
Though the implied inverse elasticities derived from NEMS appear to represent the long-term supply curve for natural gas,



¹¹ UCS (2003) has a substantially higher average inverse elasticity than most of the other studies. As noted earlier, UCS (2003) evaluated the potential impact of an RPS under a scenario of higher gas prices than in a typical AEO reference case, making this study not totally comparable to those covered in the body of this paper (the study includes a more constrained gas supply than most of the other analyses, especially in the later years).

this does not appear to be the case in the ACEEE study. The ACEEE study reports the impact of increased RE/EE over a shorter period (2004-2008), and uses a gas market model from EEA that reports impacts on a more disaggregated basis by region and by time interval. While the ACEEE study did analyze the potential impact of state and regional RE and EE deployment, Figure 9 reports the results of the national deployment scenario. As shown, early year inverse elasticities are high (at over ten). By 2008, the inverse elasticity drops to four, still over twice as large as the average long-term inverse elasticities implicit in the latest versions of NEMS.¹²

Because the other studies reviewed in this paper do not seek to present short-term impacts at the same level of disaggregation as ACEEE, it is difficult to benchmark the ACEEE results with those of other studies. The national short-term impacts forecast by ACEEE are aggressive (arguably open to critique for being too aggressive), however, and at the least should not be extrapolated into later years (but should instead be considered shorter-term impacts that are unlikely to persist for the long-term). By the same token, the ACEEE results demonstrate that the positive impacts of increased RE and EE may be more significant in the short-run than estimated by other modeling studies, whose approaches are arguably better able to address longer-term influences.



Benchmarking to Other Markets and Energy Models

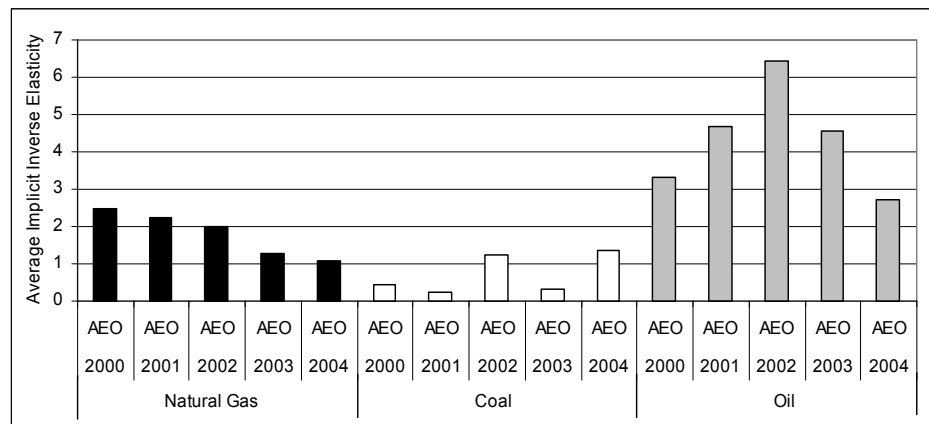
In evaluating the results presented in the previous section, it is useful to compare these inverse elasticities to those calculated for natural gas and other fossil fuels in other EIA NEMS analyses, as well as other national energy models altogether.

In particular, the RE and EE studies reviewed above are only one example of an exogenous demand shock that triggers a natural gas price response. The low- and high-economic growth scenarios published as part of the EIA's Annual Energy Outlook (AEO) each year are another such example. Low economic growth, compared to the reference case, leads to less demand for fossil fuels, while high economic growth results in the opposite effect. Figure 10 shows the range of average (2003-2020) implied inverse elasticities for natural gas, coal, and oil from Annual Energy Outlook 2000-2004, focusing on the low economic growth case relative to the reference case forecast.¹³

¹² Note that the natural gas price data used to construct the inverse elasticities implicit in the ACEEE results are projected Henry Hub prices, while the previous studies relied upon wellhead price projections. Because Henry Hub prices are typically higher than wellhead prices, inverse elasticities calculated with Henry Hub data will be lower than if wellhead prices were used.

¹³ Like natural gas, the coal market is assumed to be national, and the implicit inverse elasticity was calculated using forecasts of U.S. coal minemouth prices and total U.S. coal consumption. Oil, on the other hand, is assumed to be a world market, so the elasticity calculation used the world oil price and total world oil consumption from the AEOs.

The average implicit inverse elasticities for natural gas presented in Figure 10 are broadly consistent with – though perhaps somewhat higher than – the results of the NEMS-based EE and RE studies presented earlier – i.e., they range from 1.1 to 2.5. Figure 10 also shows that the implicit inverse elasticities for natural gas appear to



have generally decreased with successive versions of NEMS, which the EIA updates each year, perhaps implying that EIA has tried to moderate its treatment of this effect in recent years. As might be expected given plentiful and relatively inexpensive domestic coal supplies, the implicit inverse elasticity for coal is lower than that for natural gas and oil. The inverse elasticity for oil, on the other hand, is *much* higher than those for coal and gas, reflecting an assumption of highly inelastic supply.

Finding a degree of consistency between the results of the RE and EE studies presented earlier and the AEO's economic growth cases presented here should perhaps come as little surprise: with the exception of the ACEEE study, each of these studies has used the same basic model, NEMS (though again, we note that NEMS is revised annually). We therefore also sought to compare the long-term inverse elasticities implicit in NEMS with those of other national energy models. Data from a recent study by Stanford's Energy Modeling Forum (EMF 2003) allows for this comparison. In particular, this study presents the potential impact of high gas demand on natural gas consumption and price in 2010 and 2020 using seven different energy models. Table 2 presents the results of this analysis.

Table 2. Implicit Inverse Elasticities in a Range of National Energy Models

Energy Model	Natural Gas Consumption Change		Natural Gas Price Change		Inverse Price Elasticity of Supply	
	2010	2020	2010	2020	2010	2020
NEMS	3.0%	4.5%	6.4%	0.5%	2.13	0.11
POEMS	4.0%	4.3%	7.1%	7.8%	1.75	1.81
CRA	8.7%	11.9%	20.3%	11.1%	2.33	0.93
NANGAS	1.2%	3.1%	7.8%	14.8%	6.67	4.76
E2020	4.0%	8.4%	4.2%	6.3%	1.03	0.76
MARKAL	3.2%	6.3%	6.5%	13.4%	2.04	2.13
NARG	-2.3%	-0.2%	8.4%	9.7%	-3.57	-50.00

As shown, inverse elasticity estimates among these major national energy models vary substantially. Five of the seven models (NEMS, POEMS, CRA, E2020, and MARKAL) report inverse elasticity estimates that are broadly consistent with those presented earlier, while two of the models (NANGAS and NARG) create anomalous results. It deserves note, however, that several of these models (e.g., POEMS and MARKAL) rely in part on modeling inputs to NEMS,

making consistency among the models perhaps less useful than otherwise would be the case. Finally, the National Petroleum Council recently issued a national study relying on the EEA model, and whose sensitivity cases show an average implicit long-term inverse elasticity of approximately four (consistent with the 2008 ACEEE results presented earlier) (NPC 2003).

Benchmarking to Empirical Elasticity Estimates

With few exceptions, the energy modeling results reviewed previously present a consistent basic story: reducing the demand for natural gas, whether through the use of RE and/or EE or through other means, is expected to lead to lower natural gas prices than in a business-as-usual scenario. While the magnitude of the long-term implicit inverse price elasticity of supply varies substantially across model and years, the central tendency appears to be 0.75 to 2.5: a 1% reduction in national gas demand is expected to cause a corresponding wellhead price reduction of 0.75% to 2.5% in the long-term, with some models predicting even larger effects (up to a 4% reduction in long-term gas prices for each 1% drop in gas consumption).

These are merely modeling predictions, however, based on an estimated shape of a gas supply curve that is not known with any precision. It would also not be an overstatement to say that the historic ability of modelers to estimate future natural gas prices has been dismal, leading to obvious questions about the degree of confidence to place in these modeling results. It is therefore useful to benchmark these forecasts against empirical estimates of historical inverse elasticities. While empirically-derived estimates of historical inverse elasticities may not predict future elasticities accurately (the natural gas supply curve may have a different shape in 2010 than it did in 1990), and data and analysis difficulties plague such estimates, these estimates nonetheless offer a dose of empirical reality relative to the modeling results presented earlier.

Unfortunately, empirical research on energy elasticities has focused almost exclusively on the impact of supply shocks on energy *demand* (demand elasticity) rather than the impact of demand shocks on energy *supply* (supply elasticity). Our literature search uncovered only one recently published empirical estimate of the long-term supply elasticity for natural gas. Krichene (2002) estimates this long-term supply elasticity to be 0.8 (for the period 1973-1999), yielding an *inverse* elasticity of 1.25. Surprisingly, this is *larger* than Krichene's short-term inverse elasticity, estimated to be -10. Examining the 1918-1973 time period separately, Krichene estimates inverse elasticities of 3.57 in the long-term and -1.36 in the short term. Krichene estimates these elasticities using U.S. wellhead prices and international natural gas production, however, making a direct comparison to the model results presented earlier impossible.

With only one published figure (of which we are aware) for long-term gas supply elasticity, it may be helpful to review published estimates for other non-renewable energy commodities, namely oil and coal. Unfortunately, few supply constraints exist for coal, and long-term inverse elasticities are therefore expected to be lower than for natural gas. Oil production, while clearly a worldwide rather than regional market, has more in common with gas, but OPEC inserts uncompetitive influences into oil supply behavior. The comparability of natural gas, oil, and coal elasticities is therefore questionable.

Hogan (1989) estimates short- and long-term inverse elasticities for oil in the United States of 11.1 and 1.7, respectively. Looking more broadly at the *world* oil market, Krichene (2002) calculates the long-term inverse elasticity for oil to be 0.91 from 1918-1973, and 10 from 1973-1999. Ramcharan (2002) finds evidence of an uncompetitive supply market for oil for the

period 1973-1997, with a short-term inverse elasticity estimate of -5.9. For non-OPEC nations, meanwhile, he found a more competitive short-term inverse elasticity of 9.4.

The EIA (2002b) found only two studies that sought to estimate the supply elasticity for coal. The first, by Beck, Jolly & Loncar (1991), reportedly estimates an inverse elasticity for the Australian coal industry of 2.5 in the short term and 0.53 in the long term. The second study focuses on the Appalachia region of the United States (Harvey 1986), and estimates inverse elasticities of 7.1 in the short term and 3.1 in the long term.

In summary, there are few empirical estimates of supply elasticities, and data and analysis problems plague even those estimates provided above. Nonetheless, empirical estimates of historical long-term inverse elasticities for gas, coal, and oil are positive, and the modeling output presented earlier for natural gas and other non-renewable energy commodities is not wildly out of line with historical empirical estimates. Nonetheless, the range of implicit inverse elasticities of gas presented earlier is broad, and the empirical literature does not facilitate a narrowing of that range. Further, while not clearly supported by either the empirical literature or modeling output, there are some who believe that technological progress is likely to keep the long-term supply curve for natural gas relatively flat, implying a large overstatement of the magnitude of the natural gas price reduction effect in the modeling results presented earlier.

Conclusions

Concerns about the price and supply of natural gas have grown in recent years, and futures and options markets predict high prices and significant price volatility for the immediate future. Whether we are witnessing the beginning of a major long-term nationwide crisis, or a costly but shorter-term supply-demand adjustment, remains to be seen.

Results presented in this paper suggest that resource diversification, and in particular increased investments in RE and EE, have the potential to help alleviate the threat of high natural gas prices over the short and long term. Whether through gas efficiency measures, or by displacing gas-fired electricity generation, increased deployment of RE and EE is expected to reduce natural gas demand and consequently put downward pressure on gas prices. A review of the economics literature shows that this effect is to be expected, and can be measured with the inverse price elasticity of gas supply. Due to the respective shapes of long- and short-term supply curves, the long-term price impact is expected to be less significant than shorter-term impacts.

Importantly, the direct impact of this natural gas price reduction does not represent an increase in aggregate economic wealth, but is instead a benefit to consumers that comes at the expense of natural gas producers. Conventional economics does not support government intervention for the sole reason of shifting the demand curve for natural gas and thereby reducing gas prices. If policymakers are uniquely concerned about the impact of gas prices on consumers, however, then policies to reduce gas demand might be considered appropriate on wealth redistribution grounds; at a minimum, such policymakers might view reduced gas prices as a positive secondary effect of increased RE and EE deployment.

A large number of modeling studies have recently been conducted that implicitly include an evaluation of this effect. Though these studies show a relatively broad range of inverse price elasticities of natural gas supply, we also find that many of them exhibit some central tendencies. Benchmarking these results against other modeling output, as well as a limited empirical literature, we conclude that many of the studies of the impact of RE and EE on natural gas prices appear to have represented this effect within reason, given current knowledge.

Despite this, there are sometimes significant changes in the implicit inverse elasticities not only across models, but also between years within the same modeling run and between modeling runs using the same basic model. Inverse elasticities do not always remain within reasonable bounds. Combine this with the fact that the natural gas supply curve is unknown, and that the historic ability of energy modelers to predict future gas prices is dismal, and we do not believe that much weight should be placed on any *single* modeling result. More effort needs to be placed on accurately estimating the supply curve for natural gas, and in validating modeling treatment of that curve, before any single modeling result can reasonably be relied upon.

In the mean time, in estimating the impact of RE and EE on natural gas prices, it would be preferable to consider a range of natural gas elasticity estimates to bound this effect. Relying on the data summarized in this paper, we conclude that each 1% reduction in national gas demand could lead to a long-term average wellhead price reduction of 0.75% to 2.5%, with some of the models predicting even more aggressive price reductions. Reductions in the wellhead price will not only have the effect of reducing electricity rates, but will also reduce residential, commercial, and industrial gas bills. Based on the results presented in this paper, it is not unreasonable to expect that any increase in consumer electricity costs that are caused by RE and/or EE will be substantially offset by the expected reduction in delivered natural gas prices.

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