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Publication Date
2005-06-01

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Can Deployment of Renewable Energy and Energy Efficiency Put Downward Pressure on Natural Gas Prices?

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ABSTRACT

High and volatile natural gas prices have increasingly led to calls for investments in renewable energy and energy efficiency. One line of argument is that deployment of these resources may lead to reductions in the demand for and price of natural gas. Many recent U.S.-based modeling studies have demonstrated that this effect could provide significant consumer savings. In this article we evaluate these studies, and benchmark their findings against economic theory, other modeling results, and a limited empirical literature. We find that many uncertainties remain regarding the absolute magnitude of this effect, and that the reduction in natural gas prices may not represent an increase in aggregate economic wealth. Nonetheless, we conclude that many of the studies of the impact of renewable energy and energy efficiency on natural gas prices appear to have represented this effect within reason, given current knowledge. These studies specifically suggest that a 1% reduction in U.S. natural gas demand could lead to long-term average wellhead price reductions of 0.8% to 2%, and that each megawatt-hour of renewable energy and energy efficiency may benefit natural gas consumers to the tune of at least $7.5 to $20.

ACKNOWLEDGEMENTS

This work was funded by the Assistant Secretary of Energy Efficiency and Renewable Energy, Office of Planning, Budget & Analysis and Wind & Hydropower Technologies Program, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

ABBREVIATED ARTICLE TITLE

putting downward pressure on natural gas prices

KEY WORDS

renewable energy, natural gas prices, risk mitigation

1. INTRODUCTION

Renewable energy (RE) and energy efficiency (EE) have historically been supported because of their perceived economic, environmental, economic-development, and national-security benefits. Recently, extreme price volatility in wholesale electricity and natural gas markets has led to discussions about the potential risk mitigation value of these resources in the United States and elsewhere. Deepening concerns about the ability of conventional gas production to keep up with demand have also resulted in a growing number of voices calling for resource diversification (see, e.g., Bernstein, Holtberg, & Ortiz 2002; Henning, Sloan & de Leon 2003; NARUC 2003; NPC 2003a).

RE and EE are a direct hedge against volatile and escalating gas prices when they reduce the need to purchase variable-price natural gas-fired electricity generation, replacing that generation with fixed-price RE or EE resources (see, e.g., Bolinger, Wiser, & Golove 2003; Awerbuch 2003). In addition to this *direct* contribution to price stability, by displacing gas-fired generation, RE and EE may also reduce demand for natural gas and thus *indirectly* place downward pressure on gas prices.

Many recent modeling studies of increased RE and EE deployment in the United States have demonstrated that this "secondary" effect of putting downward pressure on natural gas prices 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 and/or EE deployment. As a result, this price effect is increasingly cited as justification for policies promoting RE and EE. [1]

To date, little work has focused on reviewing the reasonableness of this price-suppression effect as it is portrayed in various studies, and research has not attempted to benchmark the modeling results against economic theory. This article is a first attempt to address these two issues. Although we emphasize the impact of RE and EE on natural gas prices, we acknowledge that similar effects would result from increased utilization of other non-gas energy sources whose fuel costs are not highly correlated with the price of natural gas (e.g., coal or nuclear power, but not oil-fired generation). Additionally, while our analysis focuses on the U.S., similar effects might be expected elsewhere.

The remainder of this article is organized as follows. Section 2 reviews economic theory to explain the principles underlying the price-suppression effect. Section 3 examines many of the modeling studies conducted during the past five years that have measured the price-reduction effect, illustrating the potential impacts of RE and EE deployment on natural gas demand and wellhead prices, as well as on consumer electricity and gas bills. Section 4 calculates the long-term inverse price elasticity of natural gas supply implied by the modeling output of each of the studies, allowing us to assess the consistency of the natural gas price response among the modeling results. Section 5 compares the range of inverse price elasticities from Section 4 with results from other analyses using the Energy Information Administration's National Energy Modeling System (to test for intra-model consistency) and with other energy models altogether (to test for inter-model consistency). Section 6 compares the inverse price elasticities from Section 4 with the limited empirical economics literature that estimates the historical elasticities for natural gas and other energy commodities (to test for model consistency with the real world). In Section 7 we summarize our key findings.

2. NATURAL GAS SUPPLY AND DEMAND: A CURSORY REVIEW OF ECONOMIC THEORY

The subsections below review the economic concepts of supply and demand curves as they relate to natural gas, introduce the inverse price elasticity of natural gas supply, and discuss the nature of the benefit derived from a reduction in natural gas demand and prices.

Supply and Demand Curves

It is not clear whether today's inflated natural gas prices represent merely a short-term imbalance between supply and demand or a longer-term effect that reflects the true marginal cost of production (see, e.g., EMF 2003; Henning, Sloan & de Leon 2003; Holtberg 2002; NPC 2003a). In either case, economic theory predicts that a reduction in natural gas demand, whether caused by enhanced electricity or natural gas efficiency or by increased deployment of RE, will generally lead to a reduction in the price of natural gas relative to the price that would have been expected under higher-demand conditions.[2] This is because an inward shift of the aggregate demand curve for natural gas will lead to a lower equilibrium price for natural gas, assuming that the natural gas supply curve slopes upward. Because gas consumers are "price takers" in a market in which price is determined by aggregate 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 the form of lower electricity prices), and by reducing the price of gas delivered for direct use in the residential, commercial, industrial, and transportation sectors.

The magnitude of the price reduction will depend on the amount of demand reduction: greater displacement of demand for gas will lead to greater drops in the price of the commodity.[3] Equally important, the shape of the natural gas supply curve will 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. One generally assumes 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 (Henning, Sloan & de Leon 2003). In the long term, the supply curve will presumably flatten because supply will have time to adjust to higher (or lower) demand expectations, for example, in the form of increased (or decreased) exploration and drilling expenditures (Dahl & Duggan 1998).

Because natural gas is a non-renewable commodity, the long-term supply curve must eventually slope upward as the least-expensive resources are exhausted. 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, although both the short- and long-term supply curves slope upward, 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, on a per-MWh basis, will be greater in the short term than in the long term.[4]

In this article, we primarily emphasize the long-term impacts of RE and EE investments in the U.S. as a whole, and thus focus most of our attention on the shape of the long-term supply curve, ignoring gas transportation constraints. We take this approach for two key reasons. First, RE and EE investments are typically long term in nature, so their most enduring effects are likely to occur over 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 appear to focus on long-term, national-level impacts.

Measuring the Inverse Price Elasticity of Supply

It is convenient to use elasticity measures to estimate the degree to which shifts in natural gas demand affect the price of natural gas. The *price elasticity of natural gas supply* is a measure of the responsiveness of natural gas supply to the price of the commodity at a specific point on the supply curve. Price elasticity is calculated by dividing the percentage change in quantity supplied by the percentage change in price:

$$E = (\%\Delta Q)/(\% \Delta P), \qquad [1]$$

where Q and P denote quantity and price, respectively.

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"):

$$E^{-1} = (\%\Delta P)/(\% \Delta Q) \qquad [2]$$

Given greater supply responsiveness over the long term than in the short term, the long-term supply curve should exhibit *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 article. Before proceeding, however, it is important to address the nature of the "benefit" obtained from 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 necessarily lead to a net gain in economic welfare, but may instead represent a shift of resources (i.e., a transfer payment) from natural gas producers to natural gas consumers. As natural gas producers see their profit margins decline (a loss of producer surplus), natural gas consumers benefit through lower gas bills (a gain of consumer surplus). *Assuming a perfectly competitive and well-functioning aggregate economy*, the net effect on aggregate worldwide social welfare (producer plus consumer surplus) is zero. Wealth transfers of this type are not a standard, primary justification for policy intervention on economic grounds.

Reducing gas prices may still be of importance in policy circles, however, where it may be viewed as a positive ancillary effect of RE and/or EE deployment. Energy programs are frequently assessed using consumer impacts as a key metric.

Furthermore, the wealth redistribution effect may, in fact, result in a social welfare gain if economy-wide macroeconomic adjustment costs are expected to be severe in the case of natural gas price spikes and escalation. Such adjustment costs have been found to be significant in the case of oil price shocks and one might expect to discover a similar effect for natural gas, though research has not yet targeted this issue.[5] Awerbuch and Sauter (2005) have additionally argued that lower gas prices may result in reductions in oil demand and oil prices, indirectly reducing the macroeconomic costs of oil price shocks. Moreover, if producers are located outside of the country in question – an increasingly likely situation in the U.S. as the country becomes more reliant on imports of natural gas [especially liquefied natural gas (LNG)] – the wealth redistribution would increase aggregate domestic welfare.[6] Finally, lower natural gas prices may help preserve domestic manufacturing jobs, lead to displacement of more-polluting energy sources, and reduce the cost of environmental regulatory compliance. Given these considerations, we believe that a case can be made for considering the gas-price effects of increased RE and EE in policy evaluation, though we leave it to others to further debate this point.

3. REVIEW OF PREVIOUS STUDIES

A number of recent studies of RE and EE policies have estimated the impact of increased deployment of these resources on natural gas prices in the U.S. 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; other studies have looked at EE and environmental policies. In most cases national-level policies have been the focus of attention, but state- or regional-level policies have also been evaluated.

We compiled and evaluated information from 13 such studies: (1) five studies by the Energy Information Administration (EIA) focusing on U.S. national RPS policies, two of which model multiple RPS scenarios; (2) six studies of national RPS policies by the Union of Concerned Scientists (UCS), three 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 RPS policies in Massachusetts and Connecticut); and (4) an American Council for an Energy-Efficient Economy (ACEEE) study that explores the impact of national and regional RE and EE deployment on natural gas prices.[7] All relevant studies for which we were able to obtain comprehensive data were included.

The energy models used for these studies do not exogenously define a simple, transparent, long-term natural gas supply curve; instead, a variety of modeling assumptions and inputs are made that, when combined, implicitly define the long-term supply curve. For this reason, we must evaluate the long-term gas price effect of RE and EE by measuring the inverse price elasticity of supply in an implicit fashion – i.e., by reviewing modeling results.

The vast majority of the studies reviewed here rely on the National Energy Modeling System (NEMS), which is a national energy model developed and operated by the U.S. Department of Energy's (DOE) Energy Information Administration. The EIA, UCS, and Tellus studies were all conducted using this model. However, because NEMS is revised annually and these studies were conducted during different years, they used different versions of NEMS. In addition, some of the studies summarized in this article used modified versions of NEMS with, for example, different renewable energy and energy efficiency potential and cost assumptions. The ACEEE study used an energy model from Energy and Environmental Analysis (EEA) and, unlike the other studies, focused on the *shorter-term* impacts of RE and EE investments in easing gas prices. As such, results from the ACEEE study are not entirely comparable to those reported for the other studies.

Though most of the results presented in this paper therefore derive from a single energy model (NEMS), biasing the results somewhat, we benchmark these results against other commonly used energy models (Section 5) and against an historical literature that reviews the supply elasticity of energy commodities (Section 6). These comparisons allow greater confidence in our results.

The subsections below review the aggregate, U.S. national results from these studies: specifically national gas-consumption and price impacts, national electricity- and gas-bill impacts, and the dollar per megawatt-hour (MWh) value of RE and/or EE investments.

National Gas-Consumption and Price Impacts

Table 1 summarizes some of the key results of these studies.[8] As shown, some of the studies predict that increased RE generation (and EE, if applicable) will modestly increase retail electricity prices on a national average basis, though more recent studies have sometimes found small price reductions (due to improved renewable energy economics relative to gas-fired generation). Increased RE and EE also cause a reduction in U.S. natural gas consumption, ranging from less than 1% to nearly 30% depending on the study. This reduced gas consumption suppresses natural gas prices, with price reductions ranging from virtually no change in the U.S. average wellhead price to a 50% reduction in that price.[9]

These wellhead price reductions translate into lower gas bills for natural gas consumers and, by reducing the price of gas delivered to the electricity sector, moderate the expected RE-induced increase in electricity prices predicted by many of the studies. Though not shown here, Wiser et al. (2005) demonstrate that the absolute reduction in delivered natural gas prices for the electricity and non-electricity sectors largely mirrors the reduction in wellhead gas prices shown in Table 1. This suggests that changes in wellhead prices flow through to delivered prices for all U.S. consumers – even those consumers located in regions that do not experience significant RE and EE development – on an approximate one-for-one basis.

Focusing on those studies that *exclude* EE deployment (i.e., all but ACEEE 2003 and UCS 2001),[10] Figure 1 graphically presents the impact of increased RE generation on the displacement of U.S. gas consumption in 2020 (relative to the "base-case" forecast). Figure 2 shows the impact of increased RE generation on the U.S. average wellhead price of natural gas. As shown, increased levels of renewable energy deployment generally lead to higher levels gas displacement and greater price reductions.

The gas displacement shown in Figure 1 is affected by the amount of renewable energy added to the system (as shown in the figure), and the degree to which that renewable generation offsets gas-fired electric production. Although not shown explicitly here, RE and EE are generally expected to lead to greater reductions in gas consumption (and, therefore, prices) in the studies that rely on lower gas-price forecasts in the business-as-usual scenario. More recent studies, which often rely on higher gas-price forecasts (e.g., UCS 2004a, 2004b), generally find less gas displacement (and greater coal displacement) over time as coal outcompetes gas for new generating capacity additions; this effect can be seen in the relatively lower gas displacement and price reduction under the 20% RPS in UCS (2004a) and UCS (2004b).

This effect is shown graphically in Wiser et al. (2005), which finds that the newest studies of U.S. RPS policies – all of which feature higher base-case gas price forecasts – show that each MWh of RE displaces as little as 0.34 MWh of natural gas generation on average, as compared to some earlier studies featuring lower gas price forecasts that show an average displacement of more than 0.75 MWh. In a high-gas-price environment, this effect may mitigate the benefit of RE and EE in reducing gas prices. Although it is possible that increased RE and EE may also put downward pressure on coal prices, the elasticity of coal prices to altered demand conditions is likely to be far lower than that of natural gas (see, for example, Figure 7 later in this article), suggesting that the impact of RE and EE on coal prices is probably modest relative to their impact on gas prices.

U.S. National Electricity- and Gas-Bill Impacts

The previously presented results show 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 U.S. consumer energy bills could be positive or negative, depending on the relative magnitude of the electricity- and natural gas-bill changes.

Figure 3 presents these offsetting effects for a subset of the studies we reviewed.[11] Although there are variations among the different studies, the NPV 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 NPV of the predicted decrease in consumer natural gas bills. From an aggregate *consumer* perspective, therefore, the net consumer cost of these policies is typically predicted to be rather small, with 12 of 15 RPS analyses even showing net consumer savings (i.e., negative cumulative bill impacts).[12]

The Value of Renewable Energy, in $/MWh

By putting downward pressure on natural gas prices and bills, increased RE and EE seemingly provide a significant benefit to consumers, based on the studies reviewed here. But how large is that U.S. national impact, in dollars per MWh of renewable energy?

Considering the predicted reduction in consumer gas bills as well as an assumed one-for-one pass-through to consumers of gas cost reductions in the electricity sector, Figure 4 shows the range of consumer benefits delivered by increased RE, by study (not including those studies that also include energy efficiency investments), expressed in terms of $ per MWh of RE.

Results from these studies suggest that each MWh of RE provides, in aggregate, U.S. consumer gas savings benefits in the range of $6 to $35/MWh, with most studies showing a range of $7.50 to $20/MWh. Variations in this value are caused by different implied inverse price elasticities of natural gas supply, and by differences in the amount of gas displacement caused by RE. Even at the low end of the range, however, these consumer benefits are sizable.

4. SUMMARY OF IMPLIED INVERSE PRICE ELASTICITIES OF SUPPLY

The natural gas price response predicted by these studies can be compared by calculating the inverse price elasticity of supply implied by the results of each study, for each forecast year. This calculation requires annual data on the predicted average U.S. wellhead price of natural gas and total gas consumption in the United States for both the business-as-usual scenario and the policy scenario of increased RE and/or EE deployment.[13]

Because relying on the implied inverse elasticity for any *single* year could be misleading, Figure 5 compares the average value of the *long-term* implicit inverse elasticities among studies (excluding the ACEEE 2003 results, which are presented later).[14] Despite substantial variations among studies and results for individual years (see Wiser et al. 2005), there is some consistency in the *average* long-term inverse elasticities; the overall range is between 0.7 and 4.7, with elasticites from 13 of 19 analyses (all of which use NEMS) falling between 0.8 and 2.0.[15] This means that each 1% reduction in U.S. natural gas demand is expected to lead to a 0.8% to 2% reduction in wellhead gas prices.

Though the implied inverse elasticities derived from NEMS represent the long-term supply curve for natural gas, this may not be the case in the ACEEE study. The ACEEE study reports the impact of increased RE/EE deployment over a shorter period (2004-2008) than the other studies and uses a gas-market model from EEA that reports impacts on a more disaggregated basis by region and by time interval than NEMS, considering regional transportation and supply constraints.

Although the ACEEE study analyzed the potential impact of both state and regional RE and EE deployment, Figure 6 only reports the results of the national U.S. RE/EE deployment scenario. This figure shows that implied inverse elasticities are high, more than 10, in the early years; by 2008, the inverse elasticity drops to four, which is still more than twice as high as the average long-term inverse elasticity implicit in the latest versions of NEMS, though it is consistent with other recent long-term analyses conducted with the EEA model.[16]

Because the other studies reviewed in this article do not seek to present short-term impacts at the same level of disaggregation as ACEEE, it is difficult to compare the ACEEE results with those of other studies. The short-term impacts forecast by ACEEE are aggressive, however, and at the least should not be extrapolated to later years (but should instead be considered shorter-term impacts that are unlikely to persist). In fact, a recent paper by Costello et al. (2004) argues that recent applications of the EEA model by the National Petroleum Council (and, by extension, by ACEEE) show too little demand and supply response to changes in natural gas prices, leading to a demand-induced price response that is higher than would otherwise be expected. By the same token, the ACEEE results suggest that the positive consumer impacts of increased RE and EE may be more significant in the short run than is estimated by other modeling studies whose approaches are arguably better able to address longer-term influences.

5. BENCHMARKING AGAINST OTHER ANALYSES AND ENERGY MODELS

In evaluating the reasonableness of the above results, it is useful to compare the inverse elasticities implied by the RE/EE deployment studies to those calculated for natural gas and other fossil fuels in other EIA NEMS analyses as well as those from other national energy models.

In particular, the RE and EE studies reviewed above address only one type of 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, and high economic growth results in the opposite effect. Figure 7 shows the range of average (2003-2020) implied inverse elasticities for natural gas, coal, and oil from AEO 2000-2004, focusing on the low-economic-growth case relative to the reference-case forecast.[17]

The average implicit inverse elasticities for natural gas shown in Figure 7 are broadly consistent with the results of the NEMS-based RE and EE studies presented earlier, i.e., they range from 1.1 to 2.5, consistent with 14 of 19 of the previously presented analyses. Figure 7 also shows that the implicit inverse elasticities for gas appear to have generally decreased with successive versions of NEMS, which the EIA updates each year.[18] As might be expected given plentiful and relatively inexpensive domestic coal supplies, the implicit inverse elasticity for coal is generally lower than that for 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.[19]

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 is not surprising because, with the exception of the ACEEE study, each of these studies used NEMS. We therefore also sought to compare the long-term inverse elasticites 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, the EMF study presents the potential impact of high gas demand on U.S. natural gas consumption and price in 2005, 2010, 2015, and 2020, using seven different energy models. Using the price and demand series' provided, Table 2 presents the inverse elasticities that underlie this analysis.[20]

The table shows that inverse elasticity estimates vary substantially among the major national energy models reviewed by the Stanford study. Nonetheless, five of the seven models (NEMS, POEMS, CRA, E2020, and MARKAL) report inverse elasticity estimates that are broadly consistent with those presented earlier. Two of the models (NANGAS and NARG) report somewhat anomalous results. Some of these models (e.g., POEMS and MARKAL) rely in part on modeling inputs to NEMS, however, making consistency among the models perhaps less significant than otherwise would be the case. Moreover, the EMF report does not explain the relatively high inverse elasticities for NANGAS and NARG, or why the inverse elasticity for NEMS (and, to a lesser extent, CRA) drops substantially over time.[21]

The National Petroleum Council (NPC), meanwhile, recently issued a study relying on the EEA model; the sensitivity cases in that study show an average implicit long-term inverse elasticity (2011-2025) of approximately four (NPC 2003b). This value is consistent with the year 2007 and year 2008 ACEEE results presented earlier in Figure 6, which also relied on the EEA model. Another recent study commissioned by the National Commission on Energy Policy, and using the same EEA model, estimates inverse elasticities that are as high as 16.8 in 2010, dropping to 5.3 in 2020, and then increasing to 7.7 in 2025 (National Commission on Energy Policy 2003). These findings, as well as the earlier ACEEE results, clearly show that the EEA model predicts higher short-term and long-term inverse elasticities than several of the other commonly used national energy models; as noted earlier, Costello et al. (2004) criticize the recent application of the EEA model in part on this basis.

6. BENCHMARKING AGAINST EMPIRICAL ELASTICITY ESTIMATES

With few exceptions, the energy-modeling results reviewed previously tell a consistent, basic story: reducing the demand for natural gas, whether through the use of RE, EE, or other means, is expected to lead to lower natural gas prices than would be the case in a business-as-usual scenario. Although the magnitude of the long-term implicit inverse price elasticity of supply varies among models and years, the central tendency appears to be values of 0.8 to 2. That is, a 1% reduction in U.S. national gas demand is expected to cause a corresponding wellhead price reduction of 0.8% to 2% in the long-term, with some models predicting even larger effects (4%+ reductions in long-term gas prices for each 1% drop in gas consumption).

These are modeling predictions, however, which are based on an estimated shape of a natural gas supply curve that is not known with any precision. It is fair to say that modelers have a dismal track record in accurately estimating future natural gas prices, which raises questions about the degree of confidence we should place in these modeling results. One way to address these questions is to benchmark gas-price forecasts against empirical estimates of historical inverse elasticities. Although empirically derived estimates of historical inverse elasticities will not predict future elasticities accurately (the natural gas supply curve should have a different shape in 2010 than it did in 1990), and data and analysis difficulties plague such estimates, these estimates are nonetheless 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.[22] 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.[23]

With only one published figure (of which we are aware) for long-term natural gas supply elasticity, it may be helpful to review published estimates for other non-renewable-energy commodities, namely oil and coal. Few supply constraints exist for coal, and long-term inverse elasticities are therefore expected to be lower than for natural gas. Oil production, though clearly a worldwide rather than regional market, has more in common with gas, but the Organization of Petroleum Exporting Countries (OPEC) exerts uncompetitive influences on 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 U.S. 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. Ramcharran (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.[24]

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 Appalachian region of the U.S. (Harvey 1986) and estimates inverse elasticities of 7.1 in the short term and 3.1 in the long term.[25]

In summary, there are few empirical estimates of supply elasticities against which to benchmark the modeling output described earlier in this paper, and data and analysis problems plague the estimates described above. As important, given changes in the natural gas marketplace, there is no reason to believe that historical elasticity values will be applicable into the future. Nonetheless, empirical estimates of historical long-term inverse elasticities for gas, coal, and oil are positive, and the modeling output presented earlier for the long-term inverse elasticity of natural gas is clearly not wildly out of line with the historical empirical estimates. Still, the range of implicit long-term inverse elasticities of gas presented earlier is broad, and the empirical literature certainly does not help us narrow that range. In addition, although this view is 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.

7. CONCLUSIONS

Concerns about the price and supply of natural gas in the U.S. 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 article suggest that resource diversification, in particular increased investments in RE and EE, could help alleviate the threat of high gas prices over the short and long term. Whether by undertaking gas efficiency measures or by displacing gas-fired 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 secondary effect is to be expected and can be measured with the inverse price elasticity of natural gas supply. Because of the respective shapes of long- and short-term supply curves, the long-term price response is expected to be less significant than the shorter-term response. This secondary form of risk mitigation is additional to the direct risk-reducing benefit of replacing variable-priced natural gas with fixed-price renewable energy.

The effect of this natural gas price reduction may not entirely represent an increase in aggregate economic wealth, and may in part reflect a benefit to natural gas consumers that comes at the expense of natural gas producers. Conventional economics does not generally 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, or are concerned about the potentially harmful macroeconomic impacts of higher gas prices or on increasing imports of natural gas, then policies to reduce gas demand might be considered appropriate.

A large number of modeling studies in the U.S. have recently been conducted that at least implicitly evaluate this effect. Though these studies show a relatively broad range of inverse price elasticities of natural gas supply, and many use the same basic model, we also find that many of them exhibit some central tendencies. Benchmarking these results against other modeling output as well as a limited survey of the 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.

Nonetheless there are sometimes significant variations in the implicit inverse elasticities not only among models but also between years within the same modeling run and between runs using the same basic model. Implied 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 track record of energy modelers predicting future gas prices has not been good, and it is fair to conclude that not 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 on validating models' treatment of that curve before any single modeling result could reasonably be relied upon.

In the mean time, in estimating the impact of RE and EE on natural gas prices, we strongly recommend scenario analysis: it would be preferable to consider a range of natural gas elasticity estimates (as well as gas displacement ratios) to bound a range of potential impacts. Relying on the data summarized in this article, we conclude that each 1% reduction in U.S. national natural gas demand could reasonably be expected to result in long-term average U.S. wellhead price reductions of 0.8% to 2%, with some of the models predicting more aggressive reductions. Reductions in the wellhead price will not only have the effect of reducing wholesale and retail electricity rates but will also reduce residential, commercial, and industrial gas bills, resulting in a consumer value conservatively estimated to be equivalent to $7.5 to $20 per megawatt-hour of increased RE or EE. A national effort to serve 10% of U.S. electricity supply with non-hydro renewable sources is found to reduce average wellhead gas prices by as much as 10%. If considered in the policymaking process, values of this magnitude would support significantly more aggressive efforts to deploy renewable energy and energy efficiency technologies.

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Table 1. Summary of Results from Past RE/EE Deployment Studies

Author	RPS/EE	Increase in U.S. RE Generation TWh (% of total generation)	Reduction in U.S. Gas Consumption Quads (%)	Gas Wellhead Price Reduction $/MMBtu (%)	Retail Electric Price Increase Cents/kWh (%)
EIA (1998)	10%-2010 (US)	336 (6.7%)	1.12 (3.4%)	0.34 (12.9%)	0.21 (3.6%)
EIA (1999)	7.5%-2020 (US)	186 (3.7%)	0.41 (1.3%)	0.19 (6.6%)	0.10 (1.7%)
EIA (2001)	10%-2020 (US)	335 (6.7%)	1.45 (4.0%)	0.27 (8.4%)	0.01 (0.2%)
EIA (2001)	20%-2020 (US)	800 (16.0%)	3.89 (10.8%)	0.56 (17.4%)	0.27 (4.3%)
EIA (2002a)	10%-2020 (US)	256 (5.1%)	0.72 (2.1%)	0.12 (3.7%)	0.09 (1.4%)
EIA (2002a)	20%-2020 (US)	372 (7.4%)	1.32 (3.8%)	0.22 (6.7%)	0.19 (2.9%)
EIA (2003)	10%-2020 (US)	135 (2.7%)	0.48 (1.4%)	0.00 (0.0%)	0.04 (0.6%)
UCS (2001)	20%-2020, & EE (US)	353 (7.0%)	10.54 (29.7%)	1.58 (50.8%)	0.17 (2.8%)
UCS (2002a)	10%-2020 (US)	355 (7.1%)	1.28 (3.6%)	0.32 (10.4%)	-0.18 (-2.9%)
UCS (2002a)	20%-2020 (US)	836 (16.7%)	3.21 (9.0%)	0.55 (17.9%)	0.19 (3.0%)
UCS (2002b)	10%-2020 (US)	165 (3.3%)	0.72 (2.1%)	0.05 (1.5%)	-0.07 (-1.1%)
UCS (2003)	10%-2020 (US)	185 (3.7%)	0.10 (0.3%)	0.14 (3.2%)	-0.14 (-2.0%)
UCS (2004a)	10%-2020 (US)	181 (3.6%)	0.49 (1.6%)	0.12 (3.1%)	-0.12 (-1.8%)
UCS (2004a)	20%-2020 (US)	653 (13.0%)	1.80 (5.8%)	0.07 (1.87%)	0.09 (1.3%)
UCS (2004b)	10%-2020 (US)	277 (5.5%)	0.62 (2.0%)	0.11 (2.6%)	-0.16 (-2.4%)
UCS (2004b)	20%-2010 (US)	647 (12.9%)	1.45 (4.7%)	0.27 (6.7%)	-0.19 (-2.9%)
Tellus (2002)	10%-2020 (RI)	31 (0.6%)	0.13 (0.4%)	0.00 (0.0%)	0.02 (0.1%)
Tellus (2002)	15%-2020 (RI)	89 (1.8%)	0.23 (0.7%)	0.01 (0.4%)	-0.05 (-0.3%)
Tellus, (2002)	20%-2020 (RI)	98 (2.0%)	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 that study's forecast. All other data are for 2020.
- All dollar figures are in constant 2000$.
- The increase in U.S. RE generation reflects the TWh and % increase *relative* to the reference case scenario for the year 2020. The % figures do not equate to the size of the RPS for a variety of reasons: 1) existing RE generation and new RE generation that comes on line in the reference case may also be eligible for the RPS, and 2) the RPS is not always achieved, given assumed cost caps in some studies.
- The reference case in most studies reflects an EIA Annual Energy Outlook (AEO) reference case, 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 Rhode Island, also including the impacts of the Massachusetts and Connecticut RPS policies. All the figures shown in this table for the Tellus study, as well as ACEEE (2003), are for the predicted national-level impacts of the regional policies that were evaluated.

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

Energy Model	Implicit Inverse Price Elasticity of Supply			
	2005	**2010**	**2015**	**2020**
NEMS	1.8	2.2	0.53	0.11
POEMS	2.4	1.8	2.5	1.8
CRA	3.5	2.5	1.1	0.9
NANGAS	5.4	7.0	7.6	5.1
E2020	1.5	1.0	1.0	0.7
MARKAL	N/A	2.0	N/A	2.1
NARG	8.7	12.4	5.6	2.4

NEMS (National Energy Modeling System); POEMS (Policy Office Electricity Modeling System), CRA (Charles River Associates), NANGAS (North American Natural Gas Analysis System), E2020 (Energy 2020), MARKAL (MARKet ALlocation), NARG (North American Regional Gas model)

Figure 1. Forecasted Natural Gas Displacement in 2020

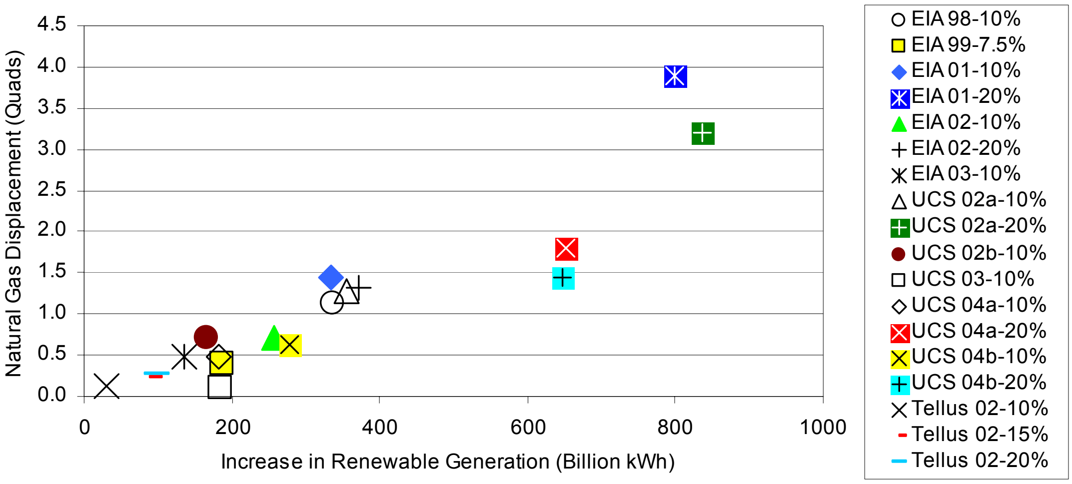


Figure 2. Forecasted Natural Gas Wellhead Price Reduction in 2020

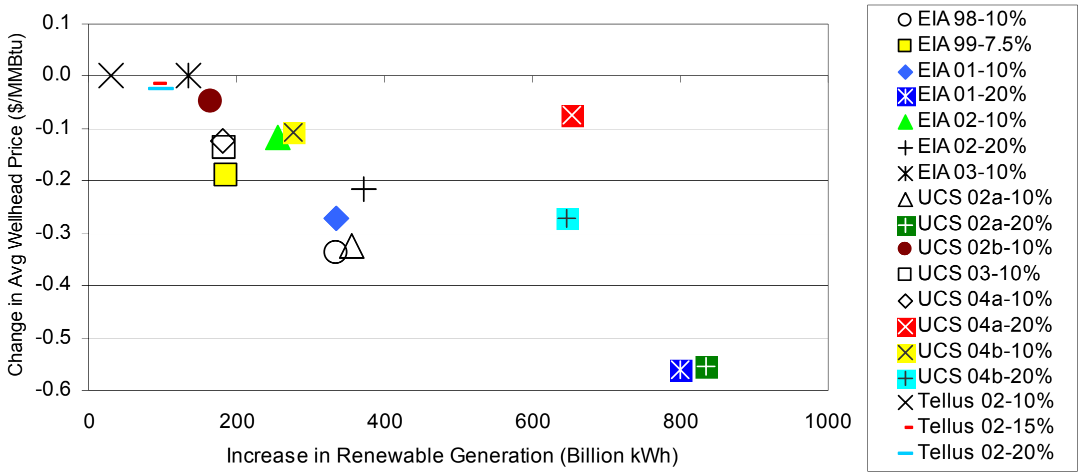


Figure 3. NPV of RPS Impacts on Natural Gas and Electricity Bills (2003-2020, 7% real discount rate)

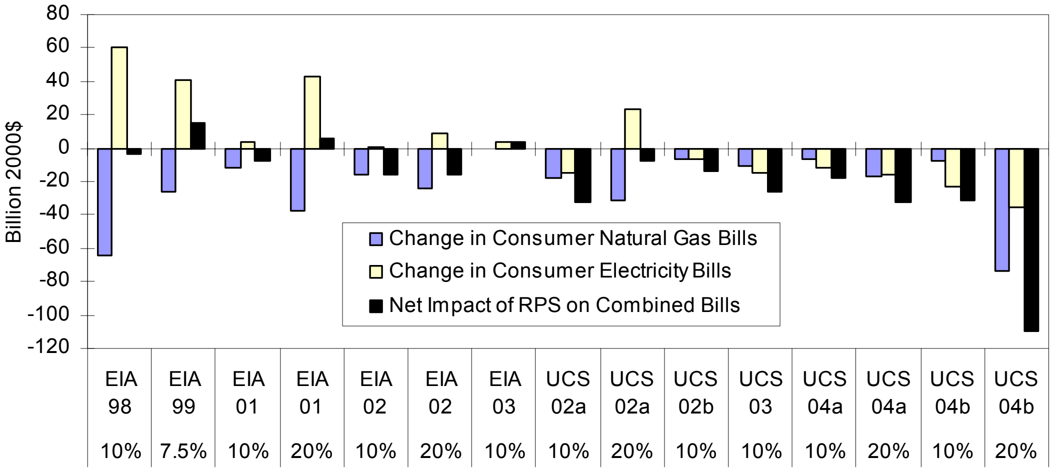
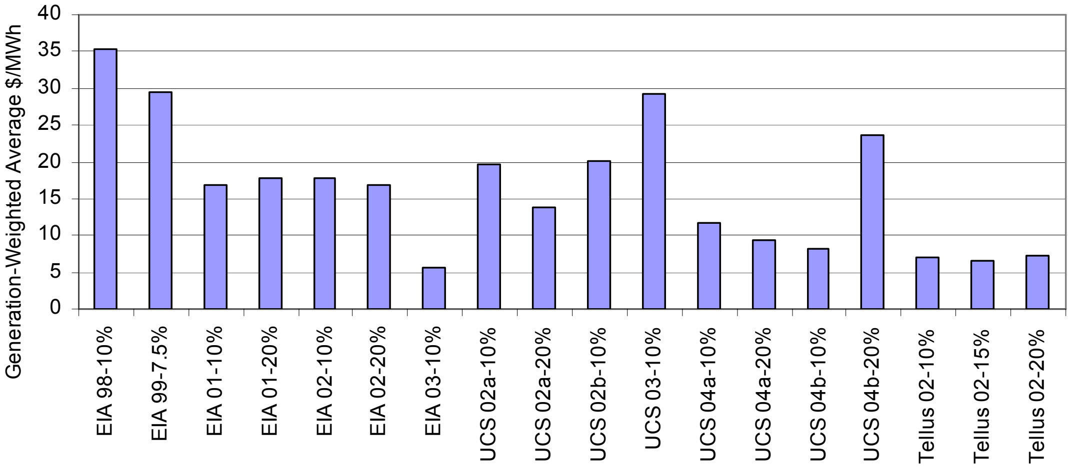


Figure 4. Consumer Gas-Savings Benefits of Increased RE Production (in $/MWh)



Note: We weight the annual gas bill savings per MWh of RE by the amount of yearly RE to derive this weighted average figure. Yearly data are averaged over the following period: from the first year in which incremental renewable energy supply exceeds 10 billion kWh (such that we ignore early year "noise" in the data) to the last year of the forecast period, either 2020 or 2025 (depending on the study).

Figure 5. Average Inverse Price Elasticities of Supply

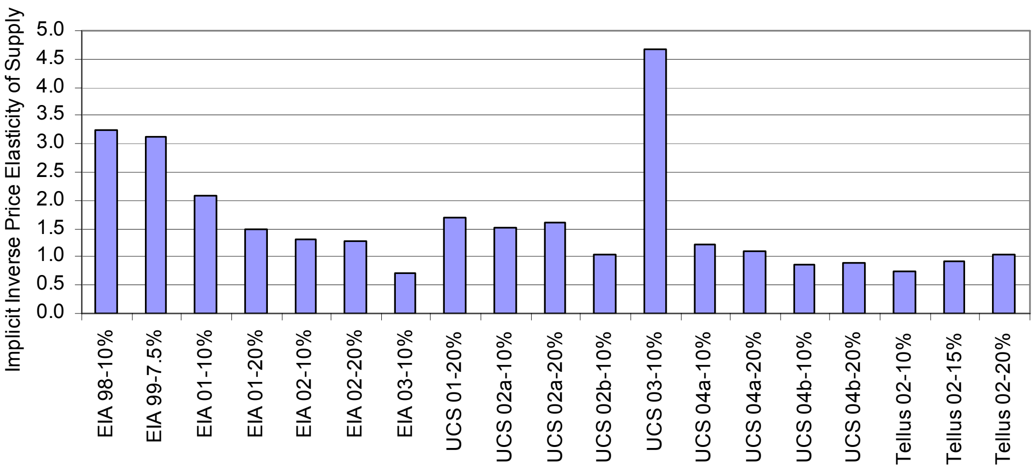


Figure 6. Implicit Inverse Price Elasticities in ACEEE (2003)

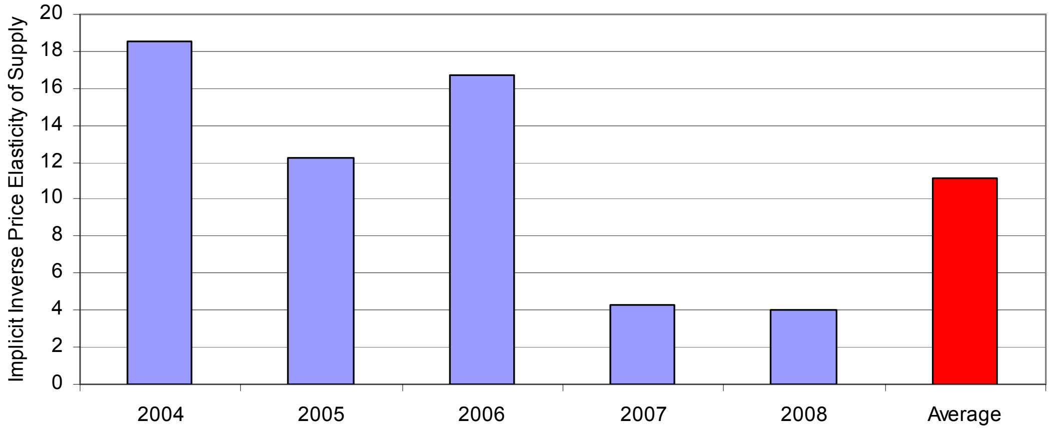
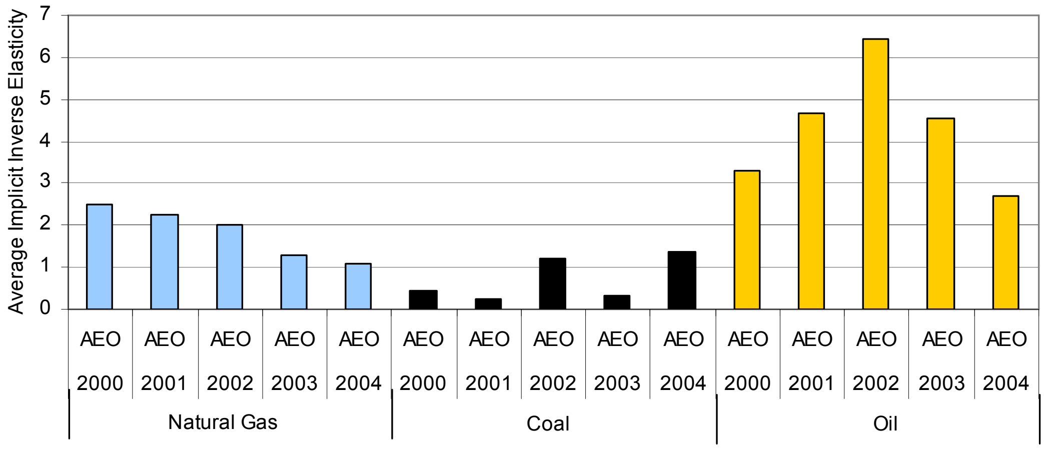


Figure 7. Average Implicit Inverse Price Elasticities for Gas, Coal, and Oil Under the AEO's Low-Economic-Growth Case



ENDNOTES

[1] These effects may not appear present in analyses of carbon reduction policies more generally, however, because such policies are likely to lead to a shift from coal- to gas-fired generation.
[2] It is worthy of note that natural gas prices may fall over time even with increasing demand if technological progress allows gas to be extracted at lower prices despite the need to extract resources from increasingly less attractive resource areas. Our argument here is simply that a reduction in natural gas demand is expected, *all else being equal*, to result in lower natural gas prices than would be seen under a higher-demand scenario.
[3] We would not generally expect any particular threshold of demand reduction to be required to lower the price of gas (unless the supply curve was flat over some of its range). Instead, greater quantities of gas savings should result in higher levels of price reduction. The impact on prices, however, need not be linear over the full range of demand reductions; it will, instead, depend on the exact – as yet unknown – shape of the supply curve in the region in which it intersects the demand curve.
[4] Note that the long-term *demand* curve is also expected to be flatter than the short-term *demand* curve (EMF 2003). This too will moderate the long-term impacts of RE and EE investments on natural gas prices.
[5] Although the literature on the macroeconomic impacts of oil-price escalation is broad, we are aware of no research that has explored the impact of natural gas price escalation. Extrapolating from studies that have looked at oil-price shocks, Brown (2003) estimates that a sustained doubling of natural gas prices might reduce U.S. gross domestic product (GDP) by 0.6-2.1% below what it otherwise would be.
[6] See Parry & Darmstadter (2003) for a recent summary of the literature on the costs of oil dependency, including macroeconomic adjustment costs and inter-country transfers.
[7] In some instances, the studies included in our analysis actually incorporated multiple sensitivity cases in addition to different RPS standard levels (e.g., different cost caps or policy sunset provisions). In these instances, we selected just one of the sensitivity cases to report here.
[8] Table 1 presents the projected impacts of increased RE and EE deployment in each study relative to some baseline. The 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 (in TWh and in % increase in renewable generation, above the baseline). The impact on renewable generation also varies because of assumed cost caps used in some studies or sunset provisions that in some studies terminate the RPS in a certain year, leading to fewer modeled renewable capacity additions in later years of the study because there are fewer years under the RPS in which to recoup investment costs. Additional variations among model runs include renewable technology and cost assumptions and the treatment of the federal production tax credit for wind power.
[9] Note that the models capture the secondary impact of the reduced price on natural gas consumption. The results presented here represent projected impacts after such secondary effects have taken place.
[10] We exclude the two studies that involve EE deployment here only to simplify the graphical results.
[11] Figure 3 shows the energy bill impacts only for the national RPS studies for which these data were available [i.e., it excludes Tellus (2002) as well as the two studies in which EE investments were also modeled].
[12] 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 3 underestimates the possible consumer benefits of a well-designed renewable energy program with less-binding cost caps.
[13] The specific calculation is:
$E^{-1} = (\text{Wellhead Price}_{\text{business-as-usual}} / \text{Wellhead Price}_{\text{policy}} - 1)/(\text{Gas Demand}_{\text{business-as-usual}} / \text{Gas Demand}_{\text{policy}} - 1)$
The inverse elasticity calculations presented here use U.S. price and quantity data under the assumption that the current 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 is relatively small compared to U.S. demand. LNG, meanwhile, remains a modest contributor to total U.S. consumption.
[14] Average inverse elasticities are calculated as the average of each year's inverse elasticity, from the first year in which incremental renewable energy production exceeds 10 billion kWh (so that we

ignore early year "noise" in the data) to the last year of the forecast period, 2020 or 2025, depending on the study.

[15] The average inverse elasticity from UCS (2003) is substantially higher than that from 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, so that study is not strictly comparable to the others covered in this paper (specifically, the UCS study includes a more constrained gas supply than most of the other analyses, especially in the later years, and so is likely measuring changes along a steeper portion of the supply curve).

[16] The natural gas price data used to construct the inverse elasticities implicit in the ACEEE results are projected Henry Hub prices; the previously mentioned studies relied on wellhead price projections. Because Henry Hub prices are typically higher than wellhead prices, inverse elasticities calculated with Henry Hub data will be somewhat lower than would be the case if wellhead prices were used.

[17] Like the natural gas market, 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.

[18] This may in part result from an assumption of increased imports from outside of the lower-48 states, including substantial increases in the role of imported LNG. Such trade may make natural gas a less-national and more-worldwide market, with prices determined in part by worldwide supply-demand dynamics.

[19] Additional research would need to be conducted to determine whether such a high inverse elasticity is plausible.

[20] The EMF scenarios modeled the impact of *increased* gas demand on price (an outward shift in the demand curve) whereas we are primarily interested in the impact of *decreased* gas demand on price (an inward shift in the demand curve). Assuming a smooth supply curve over the long term, however, the elasticities implied by an increase in demand should be essentially equivalent to those implied by a decrease in demand and thus should be comparable to what is addressed in the EE/RE studies described earlier in this paper. The data presented here primarily derive from an excel spreadsheet available on the EMF website (http://www.stanford.edu/group/EMF/publications/index.htm), which reports the results of the EMF modeling runs. The only exception is that the MARKAL results come from the EMF report itself, because data were not available for MARKAL in the spreadsheet. It should be noted that the data presented in the spreadsheet do not perfectly match the data presented in the formal EMF report; the reason for this discrepancy is not clear.

[21] We chose not to comprehensively review elasticity estimates provided in earlier models or econometric analyses (see, e.g., Huntington & Schuler 1990; Pindyck 1974), under the assumption that more recent comparisons would be most relevant. A review of national energy models by Huntington & Schuler (1990), however, reveals that elasticities implicit in energy models during the late 1980s are consistent with those in the more recent EMF (2003) study. In particular, Huntington & Schuler (1990) report inverse price elasticities of supply (projected for 2000) that range from 1.1 to 3.3 and are clustered around 1.6 to 2.5.

[22] The negative sign on the short-term inverse price elasticity implies that producers will respond to higher prices by reducing production, the opposite of what economic theory would normally expect. To explain this, Krichene (2002) postulates that natural gas production may experience economies of scale and thus a downward sloping short-term supply curve, or alternatively, that producers may recognize the inelastic nature of demand and deliberately restrain output in order to sustain any surge in prices.

[23] One additional study (reported in Dahl & Duggan 1996) estimates the short-term inverse elasticity of natural gas to range from 6.7 to 37 (Barret 1992).

[24] A number of additional studies also report short-term supply elasticities for oil (see Dahl & Duggan 1996).

[25] It may be relevant to report inverse price elasticities for other non-renewable, non-energy commodities. Although we have not systematically researched comprehensive data on these elasticities, Pindyck & Rubinfeld (1995) report a short-term inverse elasticity of four for copper and a long-term inverse elasticity of 0.67, while Fisher, Cootner & Maily (1972) report short- and long-term inverse elasticites of 2.2 and 0.6, respectively, for copper in the U.S.