Room for Improvement:
Increasing the Value of Energy Modeling for Policy Analysis

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ABSTRACT

There are expanding national discussions on a critical number of energy-related issues ranging from the importance of reducing air pollution and greenhouse gas emissions to enhancing the nation's energy security and moving towards a competitive electric utility industry. The complex interactions surrounding all of these issues have motivated the development of a relatively large number of energy-economic models to assist policy makers in the framing of appropriate policy directions. But how much do these models really inform the debate? The record of U.S. model-based energy forecasting yields evidence that such models provide biased estimates that tend to reinforce the status quo, inadequately inform policy-makers about new market potential, and serve to constrain the development of innovative policies. This paper reviews some of the reasons for this conclusion and then explores the extent to which energy-economic models may reflect a more dynamic technological diffusion process that encourages new policy development.

Introduction

In October 1973 the Arab Oil ministers imposed an oil export embargo on the United States and other countries supporting Israel during the Arab-Israel war then underway. The world oil price, which had been hovering around $3-4 per barrel, shot up to $12-15 per barrel shortly after the embargo was announced. A combination of national security concerns prompted President Nixon to proclaim a goal of energy independence for the United States — meeting all US energy needs with domestic resources by 1980.

Building on an already growing energy modeling community (see, for example, a description of various models found in Searl 1973), policy analysts turned to the economists to provide insights that might guide decisions about the nation's energy future. Questions were being asked such as what would be the consequences of modifying the historical relationship between growth in Gross Domestic Product (GDP) and energy, and what would be the economic consequences of potentially large increases in the price of energy (Reister & Edmonds 1977)? Other issues arose as well, including questions about impact on the environment (Ridker, Watson & Shapanka 1977) and ones about the effect on specific industries and regions of the country (Allen 1979).

Such questions and eventual funding gave rise to something of a cottage industry with respect to energy and economic modeling. Despite the growth in the availability of energy-economic models, however, a lingering question remains. Do the various energy and economic models promote insights that can, indeed, provide useful policy guidance? Or do they merely reflect and reinforce the status quo and, therefore, tend to limit policy innovation?

The sections that follow explore a number of issues that we hope will provide some initial insights about the impact of modeling forecasts. To provide a backdrop for such questions, the next section of the paper evaluates the early model projections compared to actual outcomes, especially those for the year 2000 (the latest for which complete historical data is now available). The subsequent section examines reasons why such projections might have proven to be so unreliable. Following that discussion, the paper then introduces what (hopefully) might be a more appropriate framework in which to evaluate policy alternatives. The paper then closes with several observations and conclusions with respect to next directions for future inquiry.

Exploring Past Scenario Projections

A review of the historical record of modeling results shows that the energy-economic models of the 1960s tended to underestimate future energy growth. By the 1970s, however, the models generated projections that seriously overestimated energy consumption and production (Craig, Gadgil & Koomey 2002). By the 1980s the projections of energy quantities became more accurate, but even near-term estimates of energy prices remained problematic and unpredictable. Moreover, a wider range of outcomes and surprises consistently emerged than might have otherwise been expected given standard confidence intervals associated with such forecasts. All of these changes in the forecasting arena point to an under-appreciation of technological change as well as producer and consumer behavior. We examine these trends in more detail.

Drawing initially on a review by Landsberg (1973), the evidence shows that projections made in the 1960s for the year 1970 were "systematically on the low side, and this despite our correct guesses on [GDP] and only a slight overestimate of population size" (*ibid*., p. 435). In 1960 total US (primary) energy consumption was 47 exajoules (EJ). Projections at that time typically indicated that energy use would rise to about 63 EJ by 1970. The actual 1970 consumption turned out to be a much larger 72 EJ, a 12 percent underestimation of energy quantities. In contrast, forecasts made in the 1970s were systematically too high. Table 1 on the following page summarizes many of those estimates (Nash 1979). The 14 separate estimates in that table include both standard forecasts and policy-based scenarios for the year 2000. The average projection for the year 2000 was 150.7 EJ compared to an actual outcome of 105.1 EJ. Hence, compared to only a decade earlier, the projections now overestimated primary energy consumption by 43 percent.

Figure 1, on the following pages, expands the comparison of future energy projections with: (i) a representation of the pre-1980 energy forecasts, (ii) the actual trend of historical energy consumption, and (iii) a series of low energy future scenarios compiled by the U.S. Department of Energy in 1980 (DOE 1980). These trends are then contrasted with the recent projection of the Annual Energy Outlook (EIA 2001).

As previously shown in Table 1, the energy models of the 1970s suggested that U.S. energy consumption might typically reach 140 EJ or more by the year 2000. Indeed, a number of prominent modelers still practicing today were then projecting that the U.S. might be consuming 170 or more exajoules by the year 2000. The actual consumption for the year 2000 is now estimated at 105 EJ.

Table 1. Energy Consumption Projections for the United States

Study/Case	2000 Projection (Exajoules)	% error
2000 Actual	**105.1**	**0%**
RFF Base Case	120.5	15%
DRI-Brookhaven Base Case	164.8	57%
DRI-Brookhaven Energy Tax Case	124.4	18%
Energy Policy Project Historical Growth Case	197.0	87%
Energy Policy Project Technical Fix Case	130.8	24%
Department of Interior	172.4	64%
Institute for Energy Analysis Low Case	107.0	2%
Institute for Energy Analysis High Case	132.8	26%
ERDA-48 Historical Base Case	174.6	66%
ERDA-48 Improved End-Use Efficiency Case	129.2	23%
ERDA-48 Coal and Shale Synthetics Case	174.5	66%
ERDA-48 Intensive Electrification Case	170.1	62%
ERDA-48 Limited Nuclear Case	166.7	59%
ERDA-48 Combination Case	144.5	38%
Average	**150.7**	**43%**

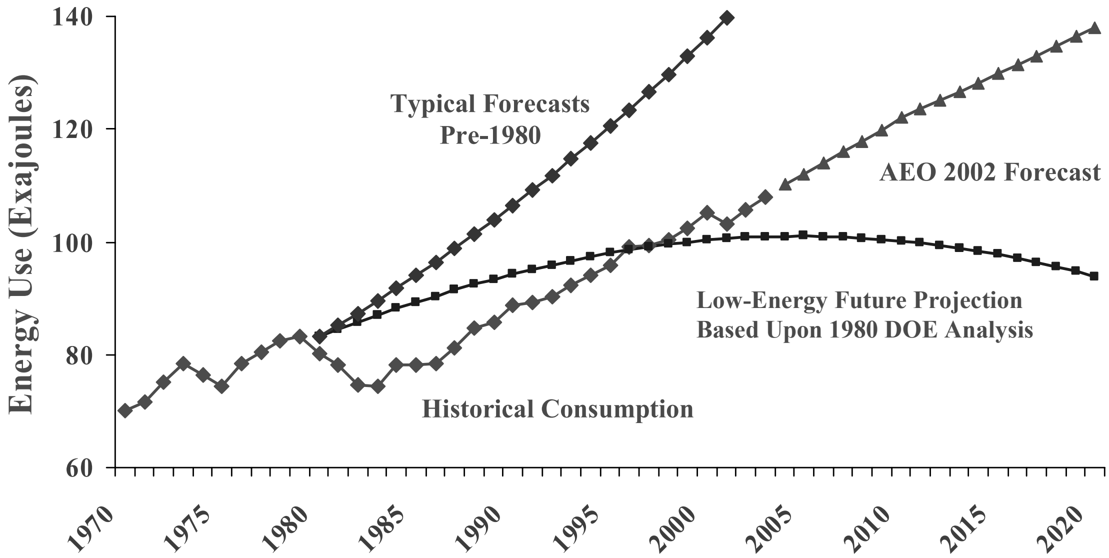
Source: Table 1 of Perry and Streiter, reprinted in Nash (1979), and EIA (2002) for the year 2000 actual consumption. Based upon a compilation of forecasts gathered by the National Economic Research Associates with publication dates between 1974 and 1977.

One interesting comparison to emerge from Figure 1 is an early attempt at characterizing just how the energy consumption might look in the event that emerging energy technologies developed significant market share. Based on a review of 10 such studies, the U.S. Department of Energy's Policy Office (1980) provided illustrative projections of possible U.S. energy consumption patterns through the year 2050. The irony here is that, both for expected and for unexpected reasons, the nation's actual energy consumption more closely reflected what was characterized in 1980 as a "low energy future" rather than what the standard forecasts were otherwise projecting at that time. As we suggest later in the paper, it appears that the difference in the early projections is an underestimation of technology, market structure, and behavioral response.

Following the oil shocks of the 1970s, energy modelers absorbed the lesson of flexibility in the face of increasing energy prices. It came to be recognized that energy prices were subject to potentially substantial increases and that the economy would, in turn, respond to such price increases. Accordingly, by the 1980s long-run consumption estimates were substantially lowered. As described in a recent retrospective by Sanstad, Koomey & Laitner

(2001), however, these moderated consumption projections were uniformly driven by projections of very high energy price levels.

Figure 1. U.S. Energy Projections: Differences in Technology Assumptions?



Source: AEO 2002, EPA estimates 2002, and 1980 DOE Policy Analysis

In examining the projections to the year 2000 of five modeling studies conducted in the early 1980s, Sanstad et al. found that all five studies of the U.S. energy system generated estimates of total energy demand for the year 2000 with an accuracy on the order of 5 percent. But they also substantially overestimated the year 2000 energy prices for all fuel types – by up to several hundred percent. The implication is that the economy "met" the lower consumption projections with much weaker price signals than were thought necessary. Sanstad et al. show how this pattern of bias in the projections can be accounted for by inferring that the early-1980s modelers grossly underestimated the rate of energy-saving technological change in the U.S. economy. They also show how this bias would have led early '80s modelers to substantially over-estimate the economic costs of future measures to reduce energy use (and implicitly, carbon emissions).

Perhaps the most prominent and influential energy/economic forecasting model in the United States is NEMS (National Energy Modeling System), maintained by the Energy Information Administration of the U.S. Department of Energy. The NEMS model is used to construct the *Annual Energy Outlook (AEO)*, published each year by the Department of Energy (EIA 2001). The EIA also conducts a regular review of the accuracy of its own forecasts. The latest review has been summarized in a recent EIA publication (Holte 2001). This review reveals (on shorter time-scales) a similar pattern to that found by Sanstad et al. (2001), that is, reasonably accurate quantity forecasts but in the context of large overestimates of energy prices.

DeCanio (2002) notes that the Holte data also shows that even in the short run, the AEO forecasts contain very little information about the actual future course of energy prices. If the forecasts had any predictive power, he suggests that a regression of the actual prices as reported by the AEO on the forecasts would show the forecasts to have some explanatory power. In other words, the year $t - 1$ forecasts of the price of oil or natural gas in year t should be significantly correlated. Yet in a regression for both oil and natural gas prices, even the forecasts made *only one year ahead* have no explanatory power (DeCanio 2002).

A different methodology to evaluate the accuracy of the EIA's forecasts was employed by Shlyakhter et al. (1994). They examined different categories of energy forecasts including projections for approximately 180 energy producing or consuming sectors contained in the Energy Information Administration's *Annual Energy Outlook* through the mid-1980's.[1] Shlyakhter and his co-authors developed a simple statistical method to compare the magnitude of forecast errors to the reported uncertainty in those same forecasts. The method compares the ex post forecast error – the difference between a forecasted price or quantity and its actual value – with the upper and lower bounds on the forecast that EIA reports at the time the forecast is made – the projected "error bounds." The result is a normalized "forecast error ratio." If the error ratio is less than 1.0, the actual price or quantity value fell within the upper or lower range of the forecasted prices or quantities. If greater than 1.0, the actual value fell outside the upper or lower range of the forecast.

Comparison of the actual outcomes to the AEO "reference case" forecasts revealed a 70 percent likelihood that the forecast error ratio was greater than 1.0 — or, in other words, fell outside the upper or lower range of the forecasts. Moreover, the likelihood that this ratio was greater than 2.0, or twice the distance from the forecast value to the upper or lower range, was 50 percent.[2] The same magnitude of forecast errors was found for each set of projections.

Applying the same technique to more recent forecasts we find similar problems. In the AEO 1996 (EIA 1996), for example, the reference case forecast for energy consumption in the year 2000 was 100.3 EJ with a lower-upper range from 98.0 to 102.8 EJ. As we've already seen, the actual consumption in the year 2000 is now estimated at 105.1 EJ. Using the Shlyakhter methodology, these results imply a forecast error ratio of 1.9. The biggest reason for such a large difference in the actual value compared to the forecasted value was the larger than expected growth in the economy which had a very large forecast error ratio of 3.7. At the same time, the error ratio associated with the change in the nation's energy intensity was 8.0.

The results of the AEO 1996 forecasts are important for two reasons. First, this is the latest forecast available to policy analysts as the United States prepared for the 1997 meetings in Kyoto that laid the groundwork for the greenhouse gas emission reductions protocol that emerged in December of that year. Second, the overly narrow forecast range provided decision makers with an unrealistic expectation of the nation's energy trajectory.

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[1] The forecasts were for 1990 projections contained in the AEOs of 1983, 1985, and 1987. There were 182, 185, and 177 energy sector variables in these three AEOs, respectively.

[2] These large forecast errors were found even after about 50 sectoral forecasts were discarded from the sample because their error ratios exceeded 100. As Shlyakhter et al. observe, "[w]e assumed that the AEO model might not be applicable in those cases and omitted them...." (*ibid*., p. 123).

The 1994 retrospective analysis by Shlyakhter and his colleagues suggests the forecast range of energy and economic variables should have been substantially larger than published. This, in turn, would have given decision makers a better sense of both uncertainty and flexibility inherent within the economy.[3] With that different insight, it is possible they would have seen a greater opportunity to shape future energy trends rather than merely respond to an expected outcome.

Why the On-Going Forecasting Errors?

Given the consistently narrow range of forecasts we might ask the question just why the actual results are so much different from the projections themselves. Based on the evidence within the published literature we identify several important reasons. The first deals with behavioral aspects of households and firms while the second deals with the role of technological change.

Successful modeling "must reflect what people and organizations actually do" (Laitner, DeCanio & Peters 2000). Unfortunately, the majority of models appear to mischaracterize the behavior of economic agents with "unsubstantiated assumptions about the characteristics of consumers and firms" (*ibid*., p. 1). Among other things, the models depict the behavior of all consumers and businesses as a group, distilling the literally millions of decisions made by millions of individuals into a few "representative agents" that do not interact with each other, except very indirectly and only in response to price signals. Moreover, the models do not reflect the many social and environmental impacts that are not reflected in the prices and transactions that are conducted within the market.

At the same time, the models tend to assume a reference case projection in which all resources are fully employed and efficiently allocated. By definition, any change in the mix of resources to protect the environment will lead to a less efficient and more costly outcome. Yet, the presumption of a trade-off between environmental and economic benefits may not provide an entirely appropriate framework for analysis of alternative energy policies (DeCanio 1997). In fact, the evidence in the economic literature indicates that the economy has the capacity to respond to a variety of policy initiatives in a more robust fashion than energy models generally credit. Boyd (2001), for instance, cites a large body of literature to conclude that improvements in energy efficiency should result in net benefits to businesses and consumers.

The idea of net energy savings associated with energy efficiency gains may be at odds with "traditional" economic models, but the evidence for improved energy and non-energy efficiency (as well as larger productivity gains) dates back to the 1950s. Indeed, as Sanstad and his colleagues have documented (*supra*), the evidence points to a frequent underestimation of the role of technological change in energy models. Moreover, a number of analysts are finding productivity gains that are at least on the same order the energy efficiency benefits for a large number of manufacturing sectors (Laitner, Ruth & Worrell

[3] This point was brought home in a recent journal article by Kydes (1999) who, based on a series of runs from the Annual Energy Outlook 1997, suggested that in the period 1996 through 2015, the annual rate of decline in the nation's energy intensity appeared to be "bounded by 1.25 percent when real energy prices are relatively stable." Yet in the period 1996 through 2000 when prices were relatively stable, the rate averaged 2.7 percent (EIA 2002), more than double the responsiveness that was otherwise anticipated in the economy.

2001; Finman and Laitner, 2001; Sullivan, Roop & Schultz 1997; and Elliott, Laitner & Pye 1997). Without a better representation of both behavioral response and technological detail in the standard models they will likely continue to provide an incomplete picture of possible outcomes.

Energy-economic forecasting is more an art than a science. There are no empirically tested assumptions, procedures, or results that can constitute the foundation for models having genuine predictive power. Econometric relationships based on historical data embody relationships that are subject to unknown changes over time (Craig et al. 2002; Koomey 2001; Koomey 2002); the theoretical foundations required to understand technological progress are yet to be established; and the behavior of individuals and organizations remains to be satisfactorily described and understood. The neoclassical abstractions of narrowly rational individuals, fully optimizing firms, and perfectly functioning markets have attractive mathematical properties, but as scientific hypotheses they do not withstand decisive tests against the evidence. It should come as no surprise that the forecasts derived from such inadequate models are uncertain and unreliable.

Modeling Future Policy Scenarios

The evidence to this point in the analysis suggests that standard energy models tend to provide an overly narrow basis on which to estimate future energy production and consumption. If so, what then are the implications for alternative policy evaluations? If the standard forecasts have problems of unreliability and only a limited capacity to capture either appropriate behavioral and/or technology responses, how can we then expect policy scenarios to be adequately evaluated within the various modeling exercises?

Krause, Baer & DeCanio (2001) completed a review of major assessments of the Kyoto treaty that provides us with a minimum framework to examine a wide variety of policy scenarios for their economic impacts. In this case, Krause and his colleagues identified six major categories of abatement strategies or impacts that should be integrated into a meaningful cost assessment before any conclusion might be drawn about an alternative trajectory for greenhouse gas emissions. The first is a uniform and consistent price signal through some form of tax and/or emission caps that are linked to a cap-and-trade market mechanism. The second is domestic market reform that includes organizational, institutional, and regulatory mechanisms to promote cost-effective technology options. The third is a shift in revenues from emission taxes or permit auctions to offset other forms of taxation. The fourth is a set of flexibility mechanisms such as international emissions trading and support for cost-effective emissions reductions within developing countries. The fifth is an assessment of health and air quality co-benefits associated with greenhouse gas emission reductions. The final category is the additional flexibility created with the policies capture the full mix of other, non-energy greenhouse gas emissions. The latter category of flexibility might also include sinks and other sequestration strategies that can reduce costs compared to an energy-related carbon emissions only strategy.

The surprising result of the study by Krause and his co-authors is that none of the major assessments of the Kyoto treaty originally included more than two of the cost minimization categories identified above. As they note, this “observation calls into question claims that the U.S. lacks affordable domestic mitigation options.” To illustrate how a more complete assessment can substantially alter the conclusions of a specific policy evaluation, Table 2 summarizes the results of nine different policy scenarios. Each scenario purports to be an evaluation of either the Kyoto Protocol or some form of greenhouse gas emission reduction strategy as it might contribute to the Kyoto target, and the subsequent economic impact of scenario on the U.S. economy as measured by changes in the nation's GDP. As each scenario captures more of the major categories of impacts identified above, the impact on GDP also begins to change.

Table 2. Comparing the Impact of Policy Gaps in Assessments of the Kyoto Targets

Scenario	Market Reform and Technology Programs	Tax Shift	International Flexibility	Inclusion Other Gases	Air Quality Co-Benefits	Realization of Kyoto Target	Percent Change in GDP for 2010
EIA Domestic Only	No	No	No	No	No	100%	-4.2%
EIA International	No	YES	YES	No	No	100%	-0.8%
EMF-16 Global Trading	No	No	YES	YES	No	100%	-0.2%
CEA Best-case Trading	No	No	YES	YES	No	100%	-0.07%
IWG Domestic Only	YES	No	No	No	No	58%	0.1%
IWG International*	YES	YES	YES	No	No	100%	0.0%
AMIGA Domestic Only	YES	No	No	No	No	52%	0.6%
AMIGA International*	YES	YES	YES	No	No	100%	0.4%
IPSEP	YES	YES	YES	YES	YES	100%	0.5%

Notes: The original data sources contained more than 100 sets of scenario results compared to the nine reflected in the table above. The purpose of this table was only to reflect the range of alternative scenarios to show how the results of a policy analysis might change when models begin to reflect more of the complete set of impacts than is typically evaluated within standard models. Since all scenarios reflect some form of a price increase as a result of either a carbon tax or a cap-and-trade mechanism that raises energy prices, no separate column shows that impact. The asterisk refers to scenarios extended from the original "domestic only" categories to include an estimated GDP impact assuming that some form of international trading provided the additional emission reductions to meet the full obligation of the Kyoto target.

Source: The information within this table is adapted from Krause et al. (2001), with supplemental data taken from IWG (2000), and Hanson and Laitner (2000).

The nine scenarios shown in Table 2 are taken from three primary sources, including Krause et al. (2001), IWG (2000), and Hanson and Laitner (2000) with supplemental information taken from the additional references as noted. The specific studies include:

1. The study of the Kyoto Protocol by the U.S. Energy Information Administration, performed in response to a Congressional request (EIA 1998);
2. The results of the 16th Energy Modeling Forum (EMF 1999), an academic forum in which a number of energy-economic models implemented different scenarios based upon normalized model assumptions;
3. The economic analysis of the Kyoto Protocol produced by the Council of Economic Advisers (CEA 1998) on behalf of the Clinton Administration;

4. A recent study completed for the U.S. Department of Energy (IWG 2000) that evaluated more than 50 policy options designed to achieve cost-effective reductions in carbon emissions;
5. A macroeconomic assessment of the IWG assumptions using the AMIGA general equilibrium modeling system (Hanson and Laitner 2000); and finally,
6. The assessment undertaken by the International Project for Sustainable Energy Paths (IPSEP) as discussed in Krause et al. (2001).

The nine sets of results summarized in Table 2 are designed to capture the range of impacts reflected in perhaps more than 100 different data sets. The range extends from the EIA assumptions of a largely non-responsive economy that incurs significant economic costs of 4.2 percent of GDP using a domestic-only carbon reduction strategy to meet the Kyoto targets to the AMIGA and IPSEP assumptions of a more responsive economy that can actually increase economic activity by about 0.5 percent while meeting the Kyoto targets.

Two important lessons emerge from a review of Table 2. The first is that the single largest influence in moving the assessments from a negative to a positive GDP impact is whether the scenario reflected a set of market reforms and technology investments that close existing energy efficiency gaps identified by Boyd (2001) and others. The second is that by including the other categories of impacts (e.g., tax shifting, international flexibility, and co-benefits) within a scenario assessment, costs are significantly reduced compared to a "price-only" mechanism favored by the standard EIA and EMF modeling exercises.

Conclusions

Physicist John Wheeler once said, "we shape the world by the questions we ask." In very much the same way, modeling exercises that fail to capture a more complete range of impacts within the policy scenarios they evaluate will tend to limit the assessment of full benefits and full costs associated with policy alternatives. In the short term, the framework provided by Krause and his colleagues (2001) provides a useful point of departure for improving modeling assumptions and interactions. This more systematic framework of both flexibility and cost-minimization strategies can provide decision makers with insights that are more robust with respect to energy and environmental policy options.

In the longer term, Laitner and his co-authors (2000) note that there are a large number of modeling advances that provide pragmatic but improved descriptions of aggregate behavior, incorporate the multiple objectives and impacts found within any shift in policy regimes, reflect the insights of "new growth theory" of endogenous technological change, and capture such influences as increasing returns and other sources of positive feedback. All of these will give rise to "a variety of path-dependent outcomes that could illustrate a range of plausible future technology scenarios" (*ibid*., p. 48). As they conclude, these "wider range of possible outcomes from models that incorporate more of human and organizational behavior implies that societies have considerable leeway in choosing the course of their future economic and technological development" (*ibid*., p. 50). Unfortunately, the standard models tend to minimize any significant possibility of positive outcomes. This, in turn, encourages a form of policy stasis rather than policy innovation that can help shape a more positive future in which the benefits of a benign environment and strengthened economy can be enjoyed by a more diverse population, both today and in the future.

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