Price Responsiveness in the *AEO2003* NEMS Residential and Commercial Buildings Sector Models

by
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This paper describes the responses of the Annual Energy Outlook 2003 (AEO2003) *versions of the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS) Residential and Commercial Demand Models to changes in energy prices, updating the results reported previously for the* Annual Energy Outlook 1999 (AEO99) *versions of the models.*[1] *Since that report, several changes have been made to the buildings models and their technology data. Own-price and cross-price elasticities, both short-run and long-run are described. Results for permanent price increases and temporary shocks are also discussed. Own-price elasticities range from -0.10 for initial year, short-run responses (commercial electricity) to -0.60 for long-run responses (residential distillate oil). Cross-price elasticities range from 0.0 to 0.86 (commercial natural gas consumption in response to changes in electricity price).*

Overview

The Residential and Commercial Demand Models are separate modules within NEMS. The two models are similar in their overall behavior, but there are differences in their internal accounting and equipment choice algorithms. In some cases, one model may include effects or exhibit behavior slightly different from the other. The discussion of model features and algorithms is intentionally brief, and only significant differences are noted here. Detailed information on both models is provided elsewhere.[2] A series of simulations using different assumptions for energy price paths is employed to develop measures for the sensitivity of energy consumption projections from the two models to changes in energy prices.

The NEMS residential and commercial models exhibit both short-run and long-run consumption responses to changes in real energy prices.[3] Responses categorized as short-run are the near-term behavioral responses of end uses that affect the utilization intensity of energy-consuming equipment when energy prices change. Examples include adjusting the thermostats of heating and cooling equipment, being more or less careful about leaving lights on or equipment running when not needed, and altering habits related to the consumption of hot water. The short-run effects in the buildings models are phased in over a 3-year period, reflecting the potential for ongoing adaptive behavior in response to persistent price changes.

Long-run price responses occur through changes in the capital stock of energy-consuming equipment installed in buildings. Energy-consuming capital goods convert energy from its raw potential into end-use services. The NEMS building models employ "stock turnover" accounting; that is, they track capital stocks by estimating what is retained from the last model year and then adding simulated equipment purchases for new construction, for the replacement of worn-out equipment,

[1]See S.H. Wade, "Price Responsiveness in the NEMS Building Sector Models," in Energy Information Administration, *Issues in Midterm Analysis and Forecasting 1999*, DOE/EIA-0607(99) (Washington, DC, August 1999).

[2]For reference case projections see Energy Information Administration (EIA), *Annual Energy Outlook 2003*, DOE/EIA-0383(2003) (Washington, DC, January 2003). For modeling assumptions and general techniques see EIA, *Assumptions to the Annual Energy Outlook 2003*, DOE/EIA-0554(2003) (Washington, DC, January 2003). For greater modeling detail see EIA, *Model Documentation Report: Residential Sector Demand Module of the National Energy Modeling System*, DOE/EIA-M067(03) (Washington, DC, January 2003); and *Model Documentation Report: Commercial Sector Demand Module of the National Energy Modeling System*, DOE/EIA-M066(03) (Washington, DC, March 2003).

[3]When prices are referenced in this paper, the reference is always to "real" energy prices, adjusted to remove any effects from general inflation in the economy. The internal calculations of the residential and commercial models operate on real prices.

and for any "retrofitting" of equipment that is still functioning but is economically obsolete.[4]

For buildings, the life of major capital equipment generally ranges from 12 years (e.g., air conditioners and heat pumps) to 30 years (e.g., boilers). As a result, full responses to energy price changes occur incrementally over an extended interval. Long-run price responses are seen in the models through projections of altered equipment purchases under different energy price regimes.[5] During periods of higher energy prices, examples of long-run responses include the purchase of more efficient lighting fixtures and bulbs, adding lighting controls like timers and motion sensors, purchasing higher efficiency space heating equipment, installing extra attic and/or wall insulation (residential model only), and switching heating fuels when price increases vary by fuel (cross-price elasticity). During periods of lower energy prices, most of the above tendencies simply reverse.[6]

Own-Price Responses

The concept of own-price elasticity is a metric that describes numerically the responsiveness of a quantity to changes in its price. It is measured simply as the percentage change in quantity divided by percentage change in price. Because price increases normally induce reduced purchases, own-price elasticities are negative quantities.[7] A sensitive or "elastic" response refers to percentage quantity changes larger in absolute value than the percentage price change (e.g., an elasticity of -2.0 indicates that the percentage reduction in quantity is twice the percentage increase in price). Empirical studies of energy demand have generally found insensitive or "inelastic" responses to energy prices, especially in the short run. That is, for a given percentage change in energy prices, there is a less than proportional percentage adjustment in energy consumption.[8] The short-run elasticity parameters in the buildings models are for each individual end use (heating, lighting, etc.). For both models, all end uses except refrigeration include a short-run price response. For all end uses with simulated equipment choices (including refrigeration), there are potential long-run adjustments in the efficiency of the equipment stock as a result of energy price changes.

Long-run responses to energy prices in the buildings models are determined endogenously. These responses occur through the interaction of installed equipment costs, equipment efficiencies, energy prices (either the "own" prices of the energy fuel used by the equipment or, where end-use services can be provided by more than one energy source, the "cross" prices of other energy sources), discount rates, maintenance costs, and annual equipment utilization rates.[9] Both models weigh all these elements, although the specific details of equipment choice differ.[10]

As described above, the long-run effects of equipment choice occur incrementally over an extended interval; and, because of the multi-year equipment lives, the effects persist once purchases are made. Thus, the effects of a temporary price increase will wear off over an extended simulation interval. For the residential model, price-induced increases in building shell efficiency (e.g., insulation, caulking, thermally-efficient windows) persist longer than other equipment purchase decisions,

[4]Equipment that is still capable of providing energy services but has operating costs (fuel and maintenance) that exceed the annualized capital and operating costs of newer equipment is "economically obsolete." The retirement and retrofitting of economically-obsolete equipment is simulated in the commercial model, adding another dimension to its potential price responsiveness.

[5]Both the residential and commercial models employ "myopic" expectations of future energy prices—that is, the current energy price is used in formulating equipment purchase decisions.

[6]The residential model insulation upgrades are an example of an effect that does not reverse in response to lower energy prices. Once installed, the insulation is assumed to last for the life of the structure.

[7]An exception is the unusual case of what are referred to as "Giffin goods." By definition, for these goods, price reductions lead to reductions in demand. Real-world examples are hard to come by, but a good purchased primarily for its "conspicuous consumption" attributes might exhibit this type of price response.

[8]C. Dahl, *A Survey of Energy Demand Elasticities in Support of the Development of the NEMS*, Contract No. DE-AP01-93EI23499 (Washington, DC, October 1993). The Dahl survey incorporated results from other survey articles and from newer studies, not reviewed previously. From prior surveys, the residential/commercial own-price elasticities for total energy ranged from -0.012 in the short run to -0.44 in the long run. Focusing on studies of aggregate time series data, demand elasticities for electricity from more recent studies averaged from -0.22 in the short run to -0.91 in the long run for residential buildings and from -0.22 in the short run to -0.82 in the long run for commercial buildings. For natural gas the averages from more recent studies were -0.13 (short run) to -0.68 (long run) for residential buildings and -0.26 (short run) to -0.99 (long run) for commercial buildings.

[9]Equipment that is used only for short periods during the year (e.g., air conditioning in northern climates) will have relatively low energy consumption and thus low energy costs. In such cases, equipment choice will be less influenced by energy prices than in areas where equipment is more heavily used.

[10]The residential model projects equipment choices using a "continuous function" approach to model the tradeoff between equipment cost and equipment efficiency, whereas the commercial model employs a "discrete algorithmic" approach. As will be seen from the simulation results, the overall behaviors of the two models are similar. For further details on equipment choice formulations, see the model documentation reports and the *AEO2003* key assumptions (cited above).

because adjustments to the shell are assumed to retire only when the housing unit decays from the stock.[11] Thus, if in subsequent years prices decline after a temporary shock, the effects of the installed shell measures will act as an additional damper on the return to pre-price shock consumption levels. This point is illustrated below, using a simulation that includes a temporary price increase. Equipment purchases other than shell adjustments have a persistence that is less than the life of the structure, and, therefore, their effects can wear off faster than the effects of shell measures after a price shock. For the equipment-related component of long-run price response there is an interval of 10 to 20 years or more before full adjustment occurs, depending on end use and equipment type (e.g., furnaces last longer than water heaters).

Another aspect of long-run price response simulated in the buildings models is what has been referred to as the "efficiency rebound" effect, which occurs when higher efficiency equipment is purchased.[12] Higher efficiency equipment lowers the marginal cost of the end-use service relative to lower efficiency equipment. Because the marginal cost of the service is reduced, a service demand response occurs, parallel to a direct price response for a good or service that is purchased directly (i.e., does not involve a consumer-purchased capital good to provide the service). Rebound effects influence consumption in the long run because of their link to equipment efficiency, which changes over an extended interval.[13]

Cross-Price Effects

Another type of price effect occurs when one fuel's consumption is affected by changes in another fuel's price. These are referred to as cross-price effects, which can be either short-run or long-run. Cross-price responses are quantified by cross-price elasticities, defined as the percentage change in the quantity of a commodity purchased, divided by the percentage change in the price of a different commodity. While own-price elasticities are expected to be negative, cross-price elasticities can be negative or positive, depending on the relationship between two goods or services.

When cross-price elasticities are positive, consumption of one good increases in response to an increase in the price of another good. This indicates that the two goods may substitute for one another. This is also what would normally be expected for energy sources, which can often "compete" (through energy stock equipment purchases) to supply end-use energy services. When cross-price elasticities are negative, the consumption of one good decreases in response to an increase in the price of another good. This type of relationship indicates that the goods are "complementary" or used together. As an example of a complementary relationship, if the price of computer equipment falls (and the quantity of computer equipment purchased increases), the quantity for electricity purchased (which provides energy for computers) increases.

An example of a short-run cross-price effect would be altering the relative amount of food prepared using electricity relative to that prepared using gas in response to a change in electricity prices (all other prices held constant). Although many homes have options to use both fuels (e.g., a home with both a gas oven and an electric microwave oven), short-run opportunities for fuel switching are rare and insignificant in residential and commercial buildings. Thus, the NEMS buildings models do not include short-run cross-price effects.

Over the long run, the buildings models do exhibit some cross-price responsiveness, because certain equipment choice decisions include the consideration of the costs of competing equipment types using different fuels (e.g., electric versus natural gas or distillate water heaters). When other fuel alternatives exist for a particular end-use service, equipment choices will be based on more than just the price of a single fuel, because the projected choices can result in measurable long-run cross-price elasticities.

Significant Model Changes Since *AEO99*

Since *AEO99*, there have been a number of modeling changes and data updates that could affect the price responsiveness of the buildings models. For *AEO99*, the

[11] A 5-percent increase in energy prices is assumed to result in a 1-percent increase in the shell efficiency index for residential buildings. No adjustment to shell efficiency is made for price declines.

[12] For the commercial model, the same end uses subject to the long-run price elasticity response are also covered by the efficiency rebound effect. For the residential model, space conditioning is covered by the rebound effect. For a discussion of the rebound effect, see J.D. Khazzoom, "Economic Implication of Mandated Efficiency Standards for Household Appliances," *Energy Journal*, Vol. 1, No. 4 (1980), pp. 21-40.

[13] Efficiency rebound effects for both the residential and commercial models are based on a parameter that results in a 0.15-percent increase in consumption for a 1-percent increase in efficiency.

residential model was based on EIA's 1997 Residential Energy Consumption Survey (RECS 1997), and the commercial model was based on EIA's 1995 Commercial Buildings Energy Consumption Survey (CBECS 1995).[14] Both surveys have since been updated: the residential model is now based on RECS 2001 and the commercial model on CBECS 1999.[15] These surveys provide the models' "base year" estimates of energy consumption by Census Division, building type, fuel, end use, and technology category. Starting from the base-year estimates, energy consumption evolves over the forecast horizon, based on growth in households or commercial floorspace, energy prices (both absolute and relative), penetration of new end uses, changes in weather from the base year, and changes in end-use equipment combinations and efficiency. Changes introduced by updating the base-year estimates could affect the price elasticities exhibited by the models through altered opportunities either for direct short-run responses or for long-run equipment-related responses.

In addition to new end-use survey data, both models also incorporate updated equipment cost and performance data on energy-consuming equipment.[16] The performance data include energy efficiency ratings and maintenance costs for current and projected equipment. As was described in the preceding sections, technology choices for new and retiring equipment in both models are dependent on capital costs, operating costs (which are directly affected by energy prices), and maintenance costs of competing end-use technologies. Because long-run responses to energy prices depend on technology choices made over the modeling horizon, changes to the technology data can affect the long-run own-price and cross-price elasticities exhibited by the models.

For both models, the short-run price elasticity response is distributed over a 3-year interval in *AEO2003*. This distribution phases in modeled behavioral changes that result from a price change, recognizing that not all behavioral adjustments occur in the same year as a price change. Because of this change, a series of short-run effects for 1, 2, and 3 years are presented, whereas for *AEO99* all the short-run effects were assumed to occur in the same year as the price increase, and a single short-run elasticity was reported.

For both models, distributed generation modules that explicitly characterize different generating technologies have been added.[17] Both the residential and commercial distributed-generation modules include photovoltaics as well as fuel-based technologies. For the commercial sector there are several natural gas-based technologies that have the potential for additional market penetration in response to changing energy prices—engines, turbines, fuel cells, and microturbines. For the residential sector, the only fuel-based technology in *AEO2003* is residential-sized fuel cells, which, although they were modeled, are in such early stages of development that they have only a negligible impact in *AEO2003*. Distributed generation now plays a minor role in the commercial sector and an even smaller role in the residential sector; however, *AEO2003* projects more than a doubling in electricity for buildings derived from such technologies by 2025, mainly as a result of programs targeting photovoltaics and projected improvements (cost reductions and efficiency gains) in distributed generation technologies.[18] Significant departures from reference case energy price paths (e.g., doubling the purchased electricity price) can stimulate adjustments to projected distributed generation and potentially result in measurable effects on both the own-price elasticity for electricity and the cross-price elasticities between electricity and natural gas.

Finally, for the residential model, a discrete building shell module has been added in order to better characterize some of the efficiency programs sponsored by the U.S. Department of Energy and the U.S. Environmental Protection Agency—specifically, Energy Star and PATH homes.[19] The choice of such homes is modeled on the basis of tradeoffs between increased construction costs and reduced energy costs. Because the development of this modeling capability also involved a review and update of the costs of achieving the shell measures, long-run elasticities can be affected in a manner parallel to effects stemming from updated end-use equipment data.

[14]See Energy Information Administration, *A Look at Residential Energy Consumption in 1997*, DOE/EIA-0632(97) (Washington, DC, November 1999); and *A Look at Commercial Buildings in 1995*, DOE/EIA-0625(95) (Washington, DC, October 1998), for more information on these surveys and results.

[15]RECS 2001 and CBECS 1999 are not yet available in printed reports. Links to the currently available information are as follows: for RECS, see http://www.eia.doe.gov/emeu/recs/recs2001/detail_tables.html; for CBECS, see http://www.eia.doe.gov/emeu/cbecs/contents.html.

[16]Arthur D. Little, Inc., "EIA Technology Forecast Updates: Residential and Commercial Building Technologies—Reference Case," Reference No. 8675309 (October 2001).

[17]See the model documentation reports (cited above) for a description of the distributed generation modules. *AEO99* modeled commercial cogeneration, but with a relatively simple single-equation representation that did not include explicit technologies.

[18]Distributed generation natural gas-based technology characterizations are from ONSITE SYCOM Energy Corporation, *The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector* (Washington, DC, January 2000). Photovoltaic technology characterizations are from U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, and Electric Power Research Institute, *Renewable Energy Technology Characterizations*, EPRI-TR-109496 (Washington, DC, December 1997).

[19]For information on Energy Star homes, see web site www.energystar.gov. For information on PATH homes, see Partnership for Advancing Technology in Housing, web site www.pathnet.org.

Elasticity Estimates and Simulations

To estimate responses to energy price changes, a series of alternative simulations were made, based on adjustments to the energy price paths from the *AEO2003* reference case.[20] The adjustments model price doublings, beginning in 2005 and continuing through the end of the model run, 2025.[21] Short-run price responses are defined here to be those that occur in the year of the price change and in the first and second years after the price change.[22] Long-run price responses are based on consumption changes in 2025. This choice in measuring long-run responses is somewhat arbitrary, and for very long-lived equipment (such as space heating), some additional responsiveness could potentially occur.[23] Table 1 reports the elasticity calculations based on simulations doubling individual energy prices over the *AEO2003* levels for all years, beginning in 2005, one fuel at a time, and then examining the results on own-fuel and cross-fuel consumption. For ease of comparison, Table 1 also presents the results previously reported for *AEO99*. A brief comparison discussion follows the discussion of the *AEO2003* results below.

Table 1. Summary of Price Responses in the NEMS *AEO2003* and *AEO99* Residential and Commercial Buildings Models

Sector and Fuel	NEMS Model Year	Short-Run Own-Price Elasticity			Long-Run Own-Price and Cross-Price Elasticity		
		1-Year	2-Year	3-Year	Electricity	Natural Gas	Distillate Fuel
Residential							
Electricity	*AEO2003*	-0.20	-0.29	**-0.34**	**-0.49**	0.01	0.00
	AEO99	-0.23			-0.31	0.03	0.00
Natural Gas	*AEO2003*	-0.14	-0.24	**-0.30**	0.13	**-0.41**	0.02
	AEO99	-0.26			0.08	-0.43	0.02
Distillate Fuel	*AEO2003*	-0.15	-0.27	**-0.34**	0.01	0.05	**-0.60**
	AEO99	-0.28			0.05	0.15	-0.53
Commercial							
Electricity	*AEO2003*	-0.10	-0.17	**-0.20**	**-0.45**	0.01	0.00
	AEO99	-0.23			-0.24	0.00	0.00
Natural Gas	*AEO2003*	-0.14	-0.24	**-0.29**	0.86	**-0.40**	0.01
	AEO99	-0.28			0.00	-0.34	0.03
Distillate Fuel	*AEO2003*	-0.13	-0.23	**-0.28**	0.08	0.75	**-0.39**
	AEO99	-0.47			0.00	0.49	-0.87
Commercial Electricity by End Use							
Core End Uses	*AEO2003*	-0.17	-0.29	**-0.36**	**-0.88**	—	—
	AEO99	-0.24			-0.31	—	—
Other End Uses	*AEO2003*	-0.03	-0.05	**-0.06**	**-0.24**	**—**	—
	AEO99	-0.24			-0.20	—	—

Sources: ***AEO2003:*** Energy Information Administration, calculated from the following price path scenarios using NEMS *AEO2003*: regeneration of the reference case price path, ELAST03.D121203B; electricity price increase case, ELAST03.D121203G; natural gas price increase case, ELAST03.D121203H; distillate fuel price increase case, ELAST03.D121203I. ***AEO99:*** S.H. Wade, "Price Responsiveness in the NEMS Building Sector Models," in Energy Information Administration, *Issues in Midterm Analysis and Forecasting 1999*, DOE/EIA-0607(99) (Washington, DC, August 1999).

[20]The simulations are based on "stand-alone" runs of the commercial and residential models. This is appropriate, since the purpose of this paper is to describe the responses of these models. In an "integrated" NEMS model run, macroeconomic effects due to large swings in energy prices could affect the calculated elasticities, possibly increasing the own-price sensitivity of the integrated model results (i.e., higher energy prices reduce economic activity, leading to further consumption decreases). Elasticities are measured using the logarithmic percentage change formula given by: $elasticity = ln(q1/q0)/ln(p1/p0)$, where $p0$ and $q0$ are base prices and quantities, and $p1$ and $q1$ represent an alternate price-quantity combination.

[21]The earlier paper, reporting *AEO99* results, was based on simulations using a 10-percent price increase instead of a price doubling. A price doubling was chosen for this report on elasticities, because price paths with such large changes are relevant to current policy analysis. Higher energy prices increase the monetary value of energy savings that accrue to higher efficiency purchases and can thus lead to greater long-run consumption responses.

[22]As mentioned above, the short-run behavioral adaptations are spread over a 3-year interval in *AEO2003*, whereas the entire effects were assumed to occur in the first year in *AEO99*. Fuel price changes also affect capital purchases for retiring equipment in the first 3 years of a simulated price change; however, no attempt has been made to isolate the capital purchase-induced component during the initial phase-in period. Capital purchases will build gradually over the forecast horizon as more equipment becomes available for replacement.

[23]The 20-year horizon was chosen because NEMS currently runs through 2025, and the initial price increase is imposed in 2005. For equipment such as commercial boilers and residential furnaces, additional long-run effects could occur beyond 2025.

Across both models, the short-run own-price elasticities for the various fuels range from -0.10 to -0.20 in the first year to -0.20 to -0.34 in the third year. Included in the estimated effects are the direct short-run effects plus the effect of altered equipment purchases and fuel choices. Long-run own-price effects indicate greater price sensitivity than short-run own-price effects in both models, reflecting the cumulative impact of altered equipment choices. Overall, long-run own-price effects for the two models are similar, with the residential model being slightly more sensitive to the distillate fuel own-price.

The difference between the short-run and long-run price sensitivity for commercial electricity can be further classified as for either "major" or "minor" end uses. Major end uses (space heating and cooling, water heating, ventilation, cooking, refrigeration, and lighting) are defined as having endogenous, price-sensitive equipment efficiency choices in addition to short-run price-sensitive usage intensity. Minor end uses (office equipment and other miscellaneous uses) do not include endogenous equipment choice. Minor end-use consumption is a function of non-price-responsive factors (e.g., floorspace growth, which is not price-responsive in these "non-integrated" NEMS simulations focusing on the buildings models) or projected additional penetration over the modeling horizon (e.g., office equipment). With no endogenous technology choice, the minor end use price responses are expected to be less sensitive than those for major end uses.[24] The calculated short-run and long-run elasticities for the major end uses range from -0.17 to -0.88. For the minor end uses, the elasticities range from -0.03 and -0.24.

Own-price responsiveness for natural gas, both short-run and long-run, is similar in the two models. For distillate, the residential model is slightly more responsive than the commercial model in both the short run and the long run.

For *AEO2003*, long-run cross-price effects exhibited by both models are always either positive or zero.[25] The positive cross-price effects indicate that different energy sources are competing for service demands. Using an arbitrary cutoff of 0.05 for noteworthy effects, significant effects for both models are found for natural gas consumption in response to a change in electricity prices and for distillate consumption in response to a change in natural gas prices. The commercial model also indicates sensitivity of distillate consumption to electricity prices.

Using distillate fuel consumption as an example, as natural gas prices increase, there are some small shifts from natural gas to distillate. Because distillate consumption is only about 13 percent of commercial natural gas consumption and 18 percent of residential natural gas consumption, any shift from natural gas to distillate will be magnified by a factor of nearly 6 for the residential sector and just under 8 for the commercial sector. For example, if 10 trillion British thermal units (Btu) of energy use shifts from commercial natural gas to distillate fuel, commercial natural gas consumption will decline by 0.3 percent and distillate consumption will increase by 2.2 percent (the percentages are 0.2 and 1.1 percent, respectively, for the residential sector). This leveraging of any movement away from natural gas causes the relatively large cross-price elasticity for distillate in response to natural gas price changes. For an increase in distillate prices, distillate's small share causes a much smaller percentage effect on gas, resulting in the nearly negligible cross-price effects for natural gas in response to changes in distillate prices.

Comparison With *AEO99* Results

The changes in simulated elasticities since *AEO99* are in many cases not very significant. Short-run behavioral effects were previously modeled as single-year responses but are now spread over 3 years. Thus, the 1-year elasticities for *AEO2003* are all smaller in magnitude than the short-run elasticities reported for *AEO99* (Table 1). The 3-year elasticities for the residential model are all slightly greater than previously reported.[26] The same holds for the commercial model, with the exception that the own-price elasticity for distillate fuel is smaller.[27]

Long-run own-price elasticities for the residential model are similar to the *AEO99* results for natural gas and distillate oil and notably larger for electricity.[28] For the commercial model, the natural gas elasticity is fairly similar to the previous results, and electricity also exhibits increased responsiveness, similar to the increase found in the residential model. The long-run distillate elasticity is of a much smaller magnitude, paralleling the change in its short-run elasticity.

[24]Examples of other miscellaneous uses include service station equipment, automated teller machines, telecommunications equipment, medical equipment, and elevators and escalators.

[25]Some negligible negative cross-price elasticities were found for *AEO99*, but in all cases they rounded to 0.00.

[26]There are also some effects of altered equipment purchases during the first 3 years beyond what would have occurred in the first-year *AEO99* short-run results. The equipment-related components during this period are not separately identified.

[27]Under the more recent technology characterizations used for *AEO2003*, distillate equipment is generally more costly relative to natural gas-based equipment than was the case for *AEO99*. This change probably is responsible for most of the reduction in long-run sensitivity.

[28]Based on results prepared for the earlier paper reporting *AEO99* results, it is estimated that roughly one-half of the reported differences in the long-run own-price elasticities of electricity for both sectors are due to the use of price doublings for analyzing the *AEO2003* models.

Cross-price elasticities for the residential model are not much different than before. There is a slight decrease in the response of distillate to the natural gas price and a slight increase in the response of natural gas consumption to the electricity price. All of the cross-price magnitudes are fairly small or negligible compared to own-price responses, and the same holds true for *AEO2003*. For the commercial model cross-price elasticities are more significant. There are two notable cases. First, the elasticity of natural gas consumption relative to the electricity price is now 0.86, where before it was negligible. This change is in part due to the addition of the distributed generation module, with opportunities for natural gas generating technologies to compete against the electricity price. The second change is an increase in magnitude of the cross-elasticity of distillate consumption relative to the natural gas price.

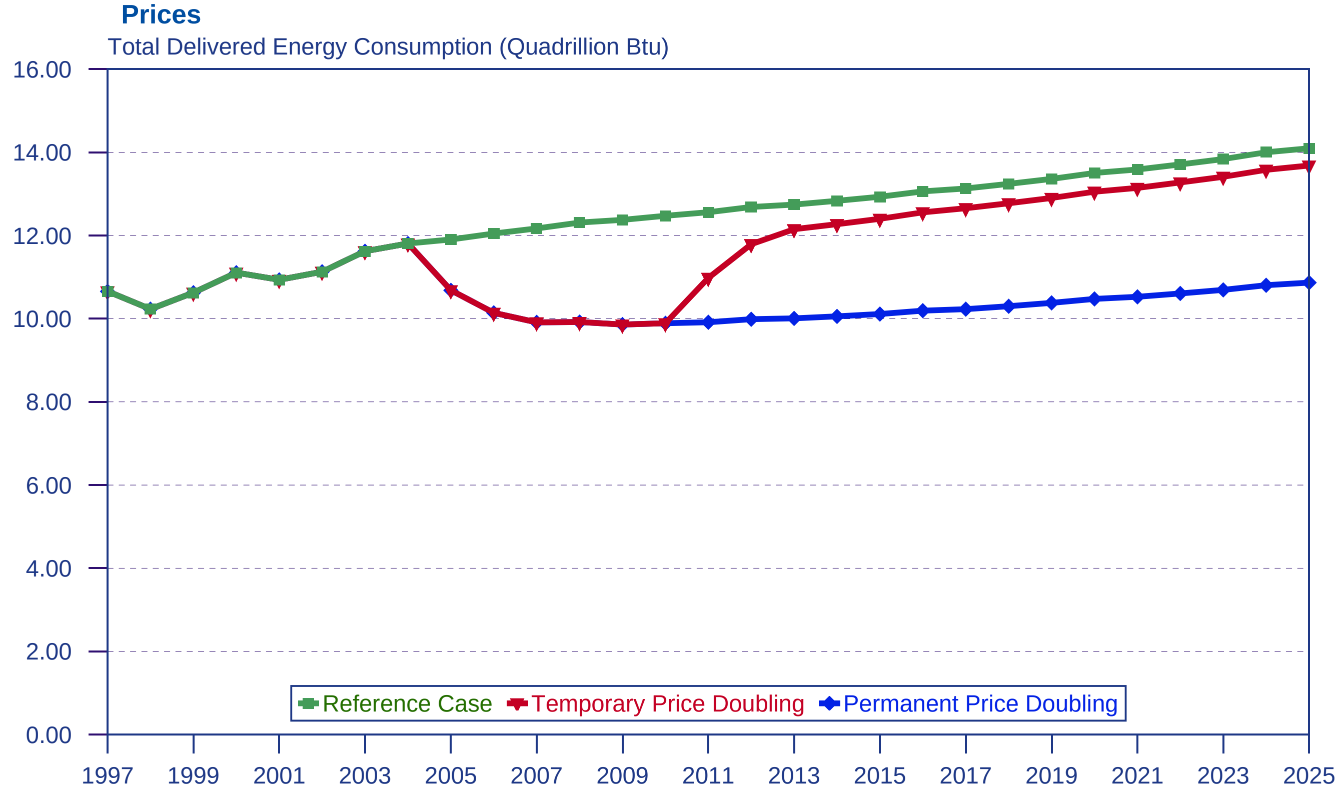
Price Shock Cases

To illustrate the responses of the NEMS buildings models under conditions other than a permanent price change, figures are provided for the residential and commercial models comparing the reference case, the permanent price doubling case (used to generate the Table 1 results) and a temporary price doubling case in which prices return to the reference case path after a 5-year period.

Reviewing the results for the residential model (Figure 1), there are two things to note. First, under persistent doubled prices, the initial reduction in energy consumption rapidly widens to a gap of approximately 2.3 quadrillion Btu by the third year, then continues gradually to widen to 3.2 quadrillion Btu by 2025. This widening of the gap is attributable to continued choices of higher efficiency equipment under the higher price regime. The gradual nature of the widening is due to different simulated equipment choices that occur as equipment is retired and then replaced. The second observation is that, for the case where prices return to the reference path, there is still a slight gap that narrows over time but does not completely disappear. The gradual narrowing reflects the return to baseline equipment choices after the shock has ended (in the NEMS buildings sector models consumers are assumed to operate under "myopic" expectations, so that past prices or shocks do not affect purchase decisions once prices return to the original path).

The gradual return of consumption occurs for the same reason that the widening in the permanently price-

Figure 1. Response of Residential Delivered Energy Demand to a Doubling of Residential Sector Energy Prices



Source: Energy Information Administration, calculated from the following price path scenarios using NEMS *AEO2003*: regeneration of the reference case price path, ELAST03.D121203B; permanent price doubling case, ELAST03.D121202J; temporary price doubling case, ELAST03.D121203K.

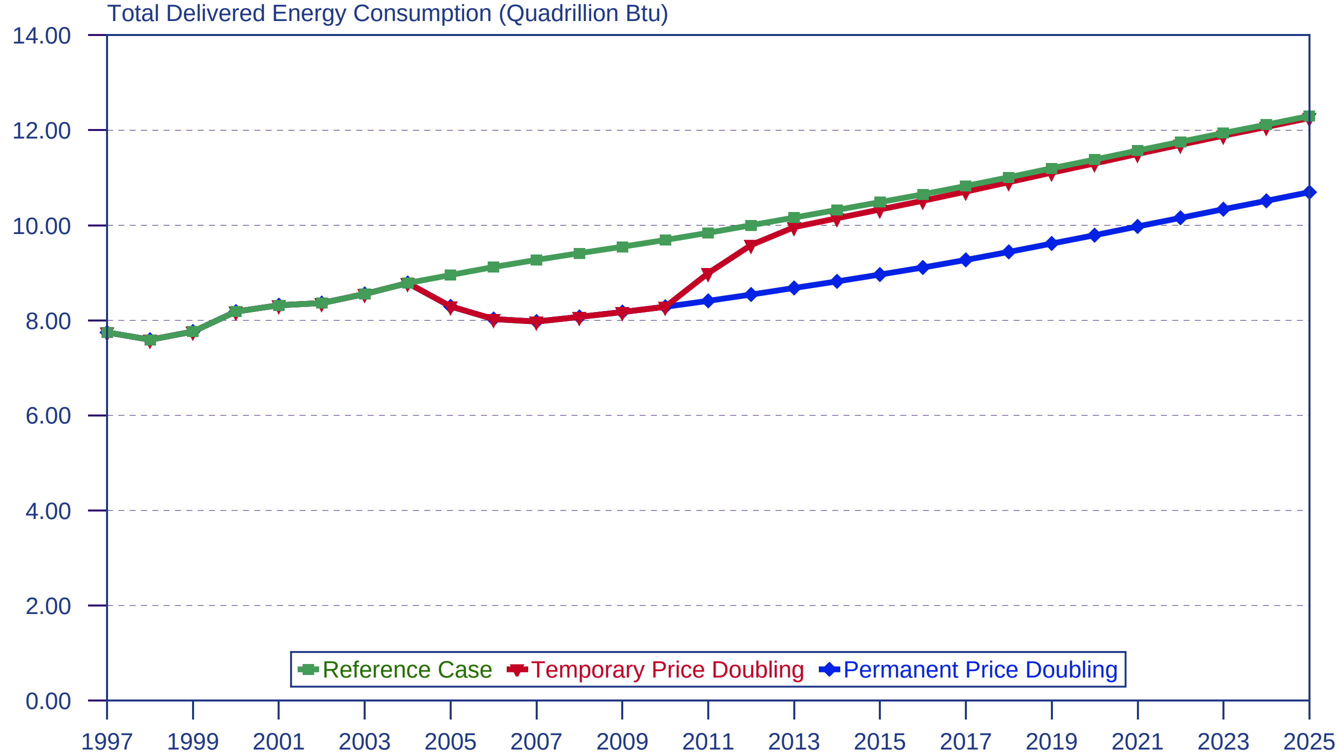
doubled case was gradual—it occurs as equipment is retired and replaced. Over the 20-year course of the simulation, the gap between the reference case and the price shock still remains, because building shells upgraded in response to higher prices during the shock period remain more energy efficient. Any installed shell efficiency measures remain in place until the buildings themselves are retired from the stock. Similar results are shown for the commercial model in Figure 2; however, the effects are not as persistent, in large part because there is no price-responsive retrofitting of building shells in the commercial model.

Illustrating Cross-Price Effects

The second set of comparison cases illustrates cross-price effects, using distillate consumption as the example for both sectors. As discussed above, the residential and commercial models respond to relative energy prices not through instantaneous fuel switching but rather through long-run changes in equipment purchases. If one fuel becomes relatively expensive, then end uses served by that fuel might switch to or favor another fuel when end-use equipment is purchased. The comparisons include the reference case and three alternative cases—one with all prices doubled, another with only the natural gas price doubled, and a third with only the distillate price doubled. As in the previous cases, all price changes begin in 2005.

Comparing these three cases against the reference case illustrates the effects of relative prices on fuel choices in the two models. Figure 3 illustrates the residential model results, focusing on the sensitivity of distillate consumption to relative price changes that lead to cross-price effects. When only the natural gas price doubles, the distillate fuel price relative to the natural gas price is halved, and equipment using distillate becomes more attractive relative to natural gas equipment for end uses that potentially can be served by either fuel. The modest increase in demand for the distillate fuel when the natural gas price doubles is the result of adjustments of modeled equipment purchases in the residential model. From Table 1, the cross-price elasticity of distillate consumption in response to the natural gas price is small in comparison with distillate's own-price elasticity (0.05 versus -0.60), indicating that own-price effects are significantly larger. Indeed, as shown in Figure 3, when the distillate price doubles, the effects on distillate consumption are much greater than when the natural gas price doubles.

Figure 2. Response of Commercial Delivered Energy Demand to a Doubling of Commercial Sector Energy Prices



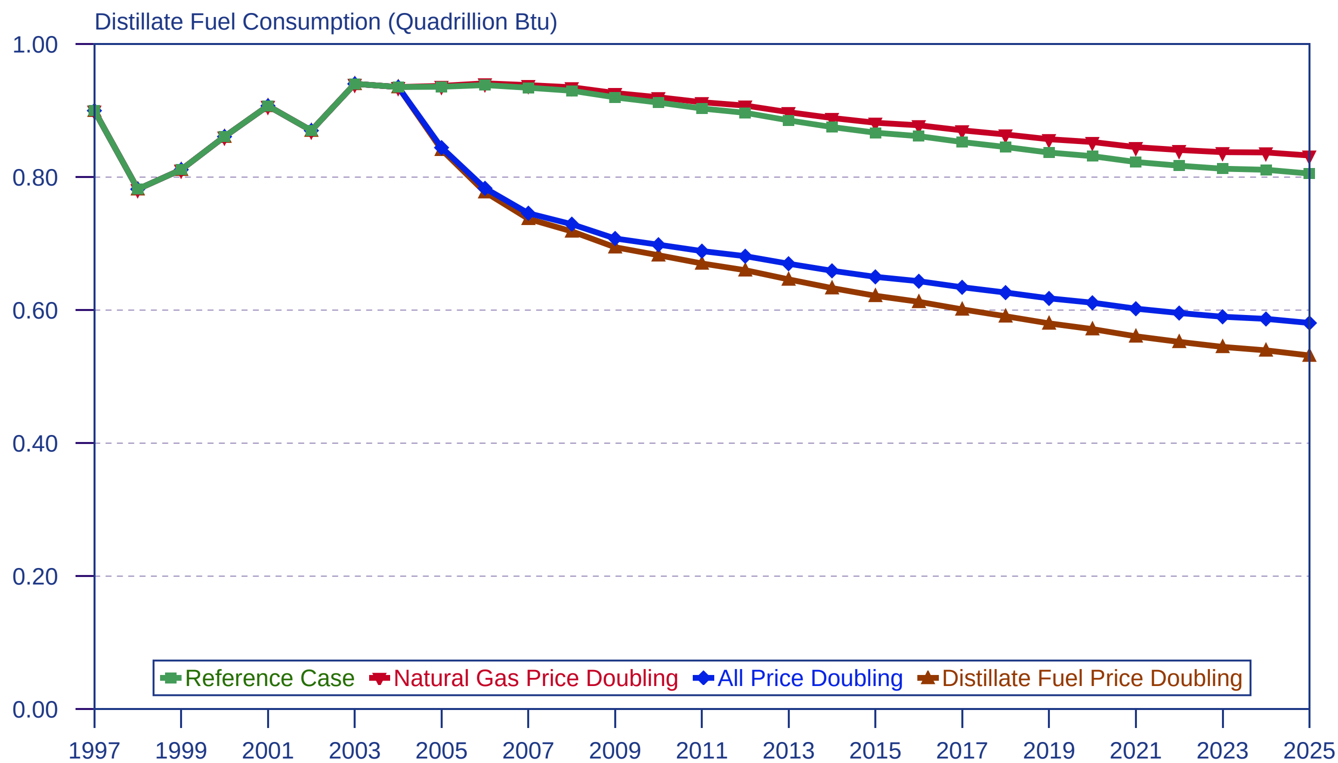
Source: Energy Information Administration, calculated from the following price path scenarios using NEMS *AEO2003*: regeneration of the reference case price path, ELAST03.D121203B; permanent price doubling case, ELAST03.D121202J; temporary price doubling case, ELAST03.D121203K.

When all energy prices double, the relationships among the prices remain the same as they are in the reference case. Thus, no additional fuel switching (beyond that already embodied in the reference) is stimulated when the price of one fuel becomes more attractive than the price of another fuel. This alternative price path (all prices doubled) produces the second-largest drop in distillate consumption compared with the reference case consumption path. Only when the distillate price alone doubles, does a greater suppression of distillate consumption occur. When only the distillate price doubles, not only the absolute price but also the relative price of distillate (compared with the prices of natural gas and other heating fuels) is doubled, further suppressing demand for distillate fuel by making natural gas and other energy sources more attractive.

Figure 4 illustrates the commercial model results for the same alternative cases shown for the residential model in Figure 3. Again, the focus is on the sensitivity of distillate consumption to price changes designed to show the impacts of relative price changes leading to cross-price effects. The results for the residential sector are generically similar to those for the commercial sector: when only the natural gas price increases, distillate fuel use is projected to grow at a substantially higher rate than in the reference case—from just under 0.5 quadrillion Btu in 2025 to more than 0.8 quadrillion Btu. This represents the switching of commercial natural-gas-fueled services to distillate-fueled services. An inspection of equipment choices indicates that distillate furnaces (meeting the 2003 standard) and high-efficiency distillate water heaters account for most of the shifting service demands. The commercial model is more sensitive than the residential model in this aspect, as could be anticipated from the larger cross-price elasticity reported for distillate fuel consumption in the commercial sector (0.75) than in the residential sector (0.05), as shown in Table 1.

When all energy prices are doubled, commercial demand for distillate fuel is also suppressed, but not by as much as in the residential model. When only distillate prices increase, the resulting suppression of distillate consumption is greater than that seen when all prices increase (by approximately 0.1 quadrillion Btu, as shown by the difference between the two bottom lines in Figure 4). This result is similar to, but slightly more sensitive than, the response of the residential model.

Figure 3. Residential Distillate Price Sensitivity: Own- and Cross-Price Effects



Source: Energy Information Administration, calculated from the following price path scenarios using NEMS *AEO2003*: regeneration of the reference case price path, ELAST03.D121203B; gas price doubling case, ELAST03.D121203H; distillate price doubling case, ELAST03.D121203I; all price doubling case, ELAST03.D121203J.

Comparisons With Other Studies

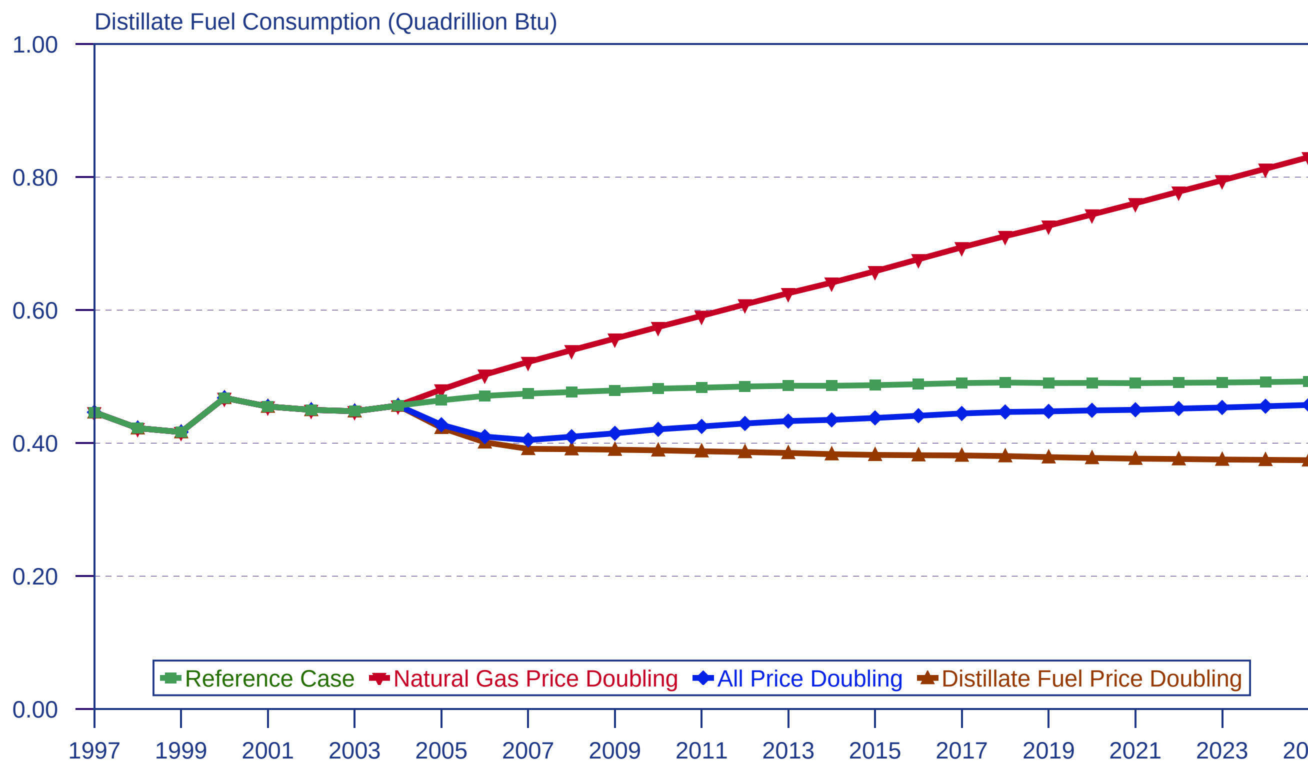
In 1993, EIA commissioned a survey of energy demand elasticities by Professor Carol Dahl,[29] as background for the development of NEMS. The survey incorporated results from previous survey articles as well as from more recent studies (referred to as "new studies" below) that had been performed after the last major surveys. The previous survey articles included data primarily from the 1970s or earlier. A limited number of the new studies included data as recent as 1990, but many of the time-series-based new studies also included pre-energy-crisis intervals, and one used data from 1937 through 1977. Thus, the "new" studies do not necessarily represent studies of more recent consumer responses to prices, which would be more relevant for comparisons with the *AEO2003* NEMS results.

In addition to short-run and long-run elasticities, Dahl also categorized the results of some models as "intermediate run" price elasticities—generally, from studies based on models that did not explicitly recognize a time path of adjustment to prices. Such models usually mix both short-run and long-run effects into a single estimate—hence the "intermediate run" nomenclature. A few of the studies reported results for the combined residential and commercial sectors, but they are not summarized here because the comparisons to the individual model results are less appropriate. Finally, because the Dahl study focused on own-price elasticities, comparisons here are limited to own-price elasticities.

Table 2 summarizes the information from the Dahl survey for the residential and commercial sectors. The table reports ranges derived from Dahl's extensive tables of individual model results. Table 2 highlights the wide range of estimates that have been made for price responses. For example, residential short-run electricity demand elasticities range from +0.57 to -0.97. For intermediate- and long-run residential electricity demand, the range is from +0.77 to -2.5.

In order to allow comparison of the NEMS elasticities presented in Table 1 with the results presented in Table 2, the ranges from Table 2 have been aggregated by sector and fuel in Table 3. Furthermore, to make the comparisons more meaningful, the ranges have been narrowed by eliminating poorly performing models that reported positive own-price elasticities. Also, because details on the scope of the new studies were readily available, only new studies with results that are

Figure 4. Commercial Distillate Price Sensitivity: Own and Cross-Price Effects



Source: Energy Information Administration, calculated from the following price path scenarios using NEMS *AEO2003*: regeneration of the reference case price path, ELAST03.D121203B; gas price doubling case, ELAST03.D121203H; distillate price doubling case, ELAST03.D121203I; all price doubling case, ELAST03.D121203J.

[29]C. Dahl, *A Survey of Energy Demand Elasticities in Support of the Development of the NEMS*, Contract No. DE-AP01-93EI23499 (Washington, DC, October 1993).

nationally representative (i.e., not based on regional, State-level, or utility-level data) are included in the Table 3 ranges.

National-level studies are the most comparable to the national estimates for NEMS shown in Table 1. Finally, because the intermediate-run elasticities generally include effects beyond the initial short-run effects, they were combined with the long-run elasticities from Table 2. Comparing the third-year (i.e., full short-run effects) results from Table 1 with those in Table 3, the NEMS short-run and long-run own-price elasticities fall within the reported overall ranges, with the exception of distillate fuel oil in the commercial model, which falls just outside the range.

Table 2. Summary of Ranges of Residential and Commercial Elasticities from Dahl (1993)

Survey Source	Fuel	Data Type	Model Class	Short Run	Intermediate Run	Long Run
Residential Sector						
Taylor (1977)	Electricity	Grouped	Grouped	-0.07 to -0.61	-0.34 to -1.00	-0.81 to -1.66
	Natural Gas	Aggregate		0.00 to -0.16		0.00 to -3.00
Bohi (1981)	Electricity	Aggregate	Static	-0.08 to -0.45		-0.48 to -1.53
	Electricity	Aggregate	Dynamic	-0.03 to -0.49		-0.44 to -1.89
	Electricity	Aggregate	Structural	-0.16		0.00 to -1.28
	Electricity	Aggregate	Other	-0.18 to -0.54		-0.72 to -2.10
	Electricity	Household	Dynamic	-0.16		-0.45
	Electricity	Household	Static	-0.14		-0.7
	Electricity	Household	Structural	-0.25		-0.66
	Natural Gas	Aggregate	Static			-1.54 to -2.42
	Natural Gas	Aggregate	Dynamic	-0.15 to -0.50		-0.48 to -1.02
	Natural Gas	Aggregate	Structural	-0.3		-2
	Natural Gas	Household	Dynamic	-0.28		-0.37
	Natural Gas	Household	Static			-0.17 to -0.45
Bohi & Zimmerman (1984)	Electricity	Aggregate	Static		0.00 to -1.57	-0.18 to -0.52
	Electricity	Aggregate	Dynamic	0.00 to -0.35		-0.26 to -2.50
	Electricity	Household	Structural	-0.20 to -0.76		
	Electricity	Household	Static		-0.55 to -0.71	-0.05 to -0.71
	Electricity	Household	Structural	+0.04 to -0.67		-1.40 to -1.51
	Natural Gas	Aggregate	Dynamic	-0.23 to -0.35		-2.79 to -3.44
	Natural Gas	Aggregate	Dynamic	-0.03 to -0.05		-0.26 to -0.33
	Natural Gas	Household	Static			-0.22 to -0.60
Dahl (1993) Prior Surveys	Fuel Oil	Grouped	Grouped	0.00 to -0.70		0.00 to -1.50
Dahl (1993) New Studies	Electricity	Aggregate	Grouped	+0.57 to -0.80	-0.11 to -1.11	+0.77 to -2.20
	Electricity	Household	Grouped	-0.02 to -0.97	-0.05 to -0.97	-0.38 to -1.40
	Natural Gas	Aggregate	Grouped	+0.02 to -0.35	1.86 to -2.41	1.56 to -3.44
	Natural Gas	Household	Grouped	-0.63 to -0.88	-0.08 to -1.80	-1.09 to -1.49
	Fuel Oil	Aggregate	Grouped	-0.10 to -0.59	-0.77 to -1.22	-1.85 to -3.5
	Fuel Oil	Household	Grouped	-0.18 to -0.19	-1.09 to -1.56	-0.62 to -0.67
Commercial Sector						
Taylor (1977)	Electricity	Aggregate	Grouped	-0.24 to -0.54		-0.85 to -1.22
	Natural Gas	Aggregate		-0.38		-1.45
Bohi (1981)	Electricity	Aggregate	Dynamic	-0.17 to -1.18		-0.56 to -1.60
	Natural Gas	Disaggregate	Static			-1.04
Bohi & Zimmerman (1984)	Electricity	Disaggregate	Grouped		0.00 to -4.56	0.00 to -1.05
	Natural Gas	Aggregate	Dynamic	0.00 to -0.37		0.00 to -2.27
Dahl (1993) Prior Surveys	Fuel Oil	Grouped	Grouped	-0.30 to -0.61		-0.55 to -0.70
Dahl (1993) New Studies	Electricity	Aggregate	Grouped	0.00 to -0.82	-0.59 to -0.98	3.36 to -4.74
	Natural Gas	Aggregate	Grouped	-0.16 to -0.37	1.92 to -2.68	0.06 to -2.27
	Fuel Oil	Aggregate	Grouped	-0.07 to -0.19	-0.3	-0.40 to -3.50

Notes: Single entries imply only one model/data combination in the category. Blanks denote no model/data combinations in the category. Static models do not include multi-period adjustments to prices. Dynamic models include lagged adjustments and distinguish short-run from long-run responses. Structural models include appliance stock data. Aggregate data usually are national or State-level data. Household data are observations on individual households. Grouped classifications denote ranges over multiple data types or model classes, or where a range of results is reported in Dahl (1993). Fuel oil elasticities from prior surveys include Taylor (1977) Bohi (1981), and Bohi and Zimmerman (1984), but the summary in Dahl (1993) aggregates across studies.

Source: C. Dahl, *A Survey of Energy Demand Elasticities in Support of the Development of the NEMS*, Contract No. DE-AP01-93EI23499 (Washington, DC, October 1993).

Summary

This report provides an updated description of how the NEMS residential and commercial models respond to changes in energy prices. Since the previous study *(AEO99)*, there have been several updates and enhancements that could affect the models' price responsiveness. For both models, the base year survey data have been updated; the projected technology characterizations have been updated; behavioral adjustments in consumption induced by short-run price changes are now distributed over a 3-year interval; and distributed generation modules with explicit technology characterizations have been incorporated. The residential model also now incorporates discrete, price-sensitive building shell characterizations added since *AEO99*.

The changes in elasticities relative to *AEO99* can be characterized briefly as follows:

- Short-run behavioral responses are now distributed over 3 years—in the first year the effects are smaller than those reported for *AEO99*. By the third year, the differences vary by sector and fuel, with the largest change being a reduction in the long-run elasticity for distillate fuel consumption in the commercial model.
- Long-run own-price effects are generally somewhat larger than those reported for the *AEO99* models. Electricity elasticities are now notably higher for both sectors, natural gas elasticities are similar to those reported for *AEO99*, and the distillate fuel elasticity is significantly lower the for commercial sector.
- Long-run cross-price effects for the residential model were generally small for *AEO99* and remain so. For the commercial model, the distillate response to a change in natural gas price is larger than that for *AEO99*, and natural gas consumption now responds to electricity price changes.

Comparing NEMS results with those from other studies, both short-run (using the 3-year elasticities that include all short-run behavioral adjustments) and long-run own-price elasticities fall within the reported overall ranges, with the exception of commercial fuel oil, which falls just outside the range.

Table 3. Summary of Adjusted Overall Residential and Commercial Buildings Sector Own-Price Responses from Dahl (1993) by Fuel

Fuel	Short-Run Elasticity	Long Run Elasticity
Residential Studies		
Electricity	0.00 to -0.80	0.00 to -2.50
Natural Gas	0.00 to -0.88	0.00 to -3.44
Fuel Oil	0.00 to -0.70	0.00 to -3.50
Commercial Studies		
Electricity	-0.17 to -1.18	0.00 to -4.74
Natural Gas	0.00 to -0.38	0.00 to -2.27
Fuel Oil	-0.30 to -0.61	-0.55 to -3.50

Source: C. Dahl, *A Survey of Energy Demand Elasticities in Support of the Development of the NEMS*, Contract No. DE-AP01-93EI23499 (Washington, DC, October 1993).