A REVIEW OF A RESIDENTIAL ENERGY END USE MODEL

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Abstract

This paper reviews an Engineering/Economic Residential Energy End Use Model, and raises some questions about the value of large-scale simulation models in forecasting or policy analysis.[1]

Keywords and phrases: forecasting, policy analysis, simulation models, energy end use models

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[1]This paper is bases in part on the results of a project to assess the model, funded by the Office of Analysis Oversight and Access, and later the Office of Statistical Standards, Energy Information Administration, Department of Energy, Washington, D.C.; the project was administered through the National Bureau of Statistics.

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1. Introduction

In a previous paper [16], we suggested that many energy models cannot be relied upon in forecasting or policy analysis. Indeed, there seems to be little hard evidence to show that such models work. And skepticism seems justified, on grounds which may be summarized as follows:

- The internal logic of the models is usually open to serious question; indeed, economic theory is not well enough developed to determine appropriate specifications for the models in any detail.
- There are major events which influence energy markets but which are beyond the scope of energy models.
- The conceptual framework of these models is fairly rigid. The models may predict the response to small and gradual price changes within a given market structure, but do not permit the structures themselves to change in response to sudden and sharp movements in relative prices.
- The models tend to have far too many parameters relative to data points.
- The quality of the data used to estimate the models is often poor or uncertain.
- Many *ad hoc* adjustments are made to the model's inputs, outputs, and intermediate results to get reasonable forecasts.
- The models are not well documented; hence their assumptions, computational procedures, and operating characteristics seem not to be very well understood, even by the analysts.

Many readers will be irritated by such criticisms. We ask them only to reflect on the argument, and then to try naming some models exempt from the difficulties listed above.

It may be useful to illustrate some of these points by a review of the Residential Energy End Use Model developed by Eric Hirst of the Oak Ridge National Laboratory (ORNL) for the Department of Energy (DOE). His overview of the model appears in Hirst (1978). A more detailed description of the model is given in a series of ORNL technical reports, listed in part I of the bibliography at the end of this paper. Other reviews of the model, which reach essentially the same conclusion as the present one, may be found in Herbert (1980), McFadden (1981), and Orcutt (1981).

The model is widely used. Many utilities base their demand forecasts on this model or its successors. The California State Energy Commission uses a similar model. The 1979 report by the Committee on Nuclear and Alternative Energy Sources of the National Academy of Sciences (CONAES) used the ORNL model as a major tool for policy analysis. Likewise, the Department of Energy routinely used the model to make forecasts and to do policy analysis.

The overall conception of the energy markets embodied in the model may seem reasonable to many readers: indeed, it seems so to us. The implementation, however, is much less satisfactory. In detail, the model is just a set of patches. On our view, this is almost inevitable, for two reasons:

- There is no detailed economic theory to guide the specification of the model.

. There are not enough data from which to estimate the parameters in the model.

Furthermore, we find that the relationship between the behavior of the model and the behavior of the energy market has not been demonstrated in any convincing way. Indeed, the multiplicity of parameters in the model makes it almost exempt from any empirical discipline. To make these arguments, we must present the model in substantial detail, in sections 2 through 7 below. Some statistical issues will be discussed in sections 8 through 10; our conclusions will be presented in section 11.

Finally, we wish to note that the Oak Ridge modeling group has made substantial revisions to the model since this report was written, and the new version seems to be much more coherent, although we have not had a chance to review it in any detail.[1]

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[1]For information, contact Dan Hamblin, Data Methods Group, Energy Division, ORNL, Oak Ridge, Tennessee.

2. An overview of the model

The model forecasts what the demand by the residential sector in each of the ten DOE regions would be in a future year for each type of fuel, as a function of a vector of region-specific future prices and other variables. The basis for the model is the idea that households consume energy in the form of various fuels through the operation of equipment for various end-uses: e.g., households consume oil in furnaces for space-heating, or gas in stoves for cooking. The amount of energy consumed depends on the operating environment (e.g., the size of the house), the technological characteristics of the equipment (e.g., efficiency), and the intensity of utilization. The stock of housing units matters, as does the stock of equipment; so the renewal of these stocks must be considered. Total residential energy consumption can be obtained by adding over the various fuel and end-use combinations. In the main, the various fuel and end-use combinations are treated independently by the model.

The model does not keep track of individual units, but aggregates similar pieces of equipment, and similar households, into categories: within each category, units are treated as if they were identical. Naturally, this produces aggregation errors, whose severity depends on the heterogeneity within the categories. The choice of categories is important, and the classifications used will be outlined in this section, as well as the method for projecting consumption within each cell of the cross-classification.

The model distinguishes four fuels:

electricity	oil
natural gas	other/none

There are eight end uses:

space-heating	refrigeration
air-conditioning	food freezing
water-heating	lighting
cooking	other

Energy use by a piece of equipment is considered to depend on the sort of house it is in. Therefore, in the model, the housing stock is disaggregated into three "types" of units:

single-family multi-family mobile homes.

Likewise, energy use by a piece of equipment is also considered to depend on its technological characteristics. In the model, pieces of equipment produced in different years have different efficiencies, and likewise for housing units. Thus, the model should distinguish vintages. In fact, the model only distinguishes two "states" of housing:

- old (built in previous periods)
- new (built in the current period)

Thus, all housing vintages prior to the current one are aggregated into the "old" category.[1]

The amount of each fuel consumed for each end-use is projected separately for each housing type and state. The number of cells created this way is

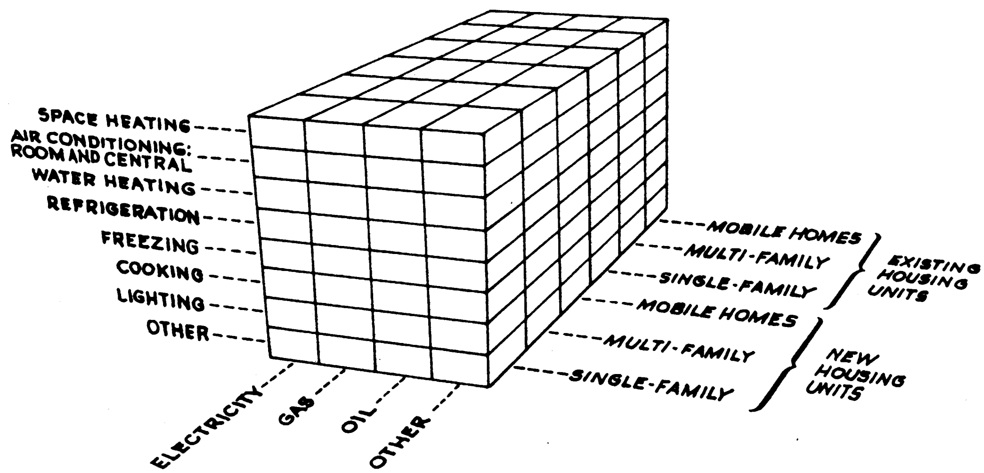
$$4 \text{ fuels} \times 8 \text{ end-uses} \times 3 \text{ types} \times 2 \text{ states} = 192.$$

In principle, then 192 components of demand are projected separately

[1]The code does not seem to implement the idea of making projections of consumption separately by housing state, and this conflicts with the documentation; we will follow the documentation.

and summed: see figure 1 for a graphical representation of this accounting framework.[1]

Figure 1. The accounting framework.
Source: ORNL/CON-24, p. 51



Within each cell, a "Q-equation" is used to forecast energy consumption. The model starts with the quantity consumed in the base-year 1970, and multiplies this by factors to account for changes in

- the number of households
- the fraction of households having a given type of equipment
- average efficiency of the given type of equipment
- average utilization rate of the given type of equipment.

For space-heating and air-conditioning, there are also factors to

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[1] Many cells are assumed to be empty: for instance, gas-fired refrigerators do not appear in the model. Unfortunately, the documentation does not say exactly which cells are assumed to be empty—or why.

account for changes in the size and thermal efficiency of the housing units. These factors are calculated using updating formulas. For example, the average efficiency of equipment this year is a weighted average of the average efficiency last year and the average efficiency of new equipment. Thus, the dynamics of the model are based on changes in the stock of energy-using equipment, whose treatment will now be indicated.

Over time, equipment (and houses) break down and must be replaced. Also, new houses must be built to satisfy the demands of an expanding population; new houses must be supplied with equipment for the various end uses (electric space-heaters, gas stoves, etc.). In the model, break-downs occur at a constant rate depending only on the end-use. For example, space-heaters (whether electric, oil-fired, or gas-fired) break down on the average every fifteen years. Both for equipment and housing units, a simple identity holds: the number of units existing in one year equals the number existing in the previous year plus the number produced minus the number scrapped.

Builders of new houses must choose one fuel for each end use; e.g., the furnace for space-heating can be electric, oil-fired, gas-fired, or other-fired. Likewise, the owner of an old house with a piece of equipment which has just broken down must again choose a fuel for that end-use: e.g., if an electric stove breaks down in period t, the owner gets to choose a new stove, which may be either electric or gas or other-fired. The fraction choosing a specific fuel is called a "market share" or a "saturation."

In short, this is a vintage capital model with exponential scrapping, disaggregated by fuel type, end use, housing type and state, and region. In the model, energy use changes over time because the stock of equipment and housing changes, as does the utilization rate.

The model can be considered in detail under the following headings:

- the Q-equations, which forecast the quantities of fuels consumed in each cell.
- the efficiencies submodel, which determines efficiencies of new equipment and structures.
- the CN-equations, which forecast fuel choices for new equipment.
- the U-equations, which forecast intensity of usage.
- the housing submodel, which forecasts the number and size of new housing units.

Each will be discussed in turn.

The original model was national, but the version running at EIA is regional. In effect, there are ten models, one for each DOE region. The equations are structurally identical, and many of the parameters are equal across all ten regions. However, many other parameters are region-specific.[1]

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[1] This review focuses on Version 5 of the model, as disaggregated to DOE regions. This was the version used by the Energy Information Administration (EIA) to make the forecasts reported in [30].

3. The Q-equations

Cross-classifying according to fuel-type, end-use, housing-type, and housing-state, the model ultimately distinguishes about a hundred nonempty categories of energy-using equipment. The model produces forecasts of energy use in each year for each such category. The method is similar for all categories, but space-heating and air-conditioning are a bit different: in these categories, energy consumption depends on the floor area of the housing unit, and the thermal efficiency of the shell. "Other/none"—burning equipment is handled quite differently, so it is excluded from this discussion.

To illustrate the method used by the model, consider only one example: oil used for space-heating in old single-family homes. The ORNL notation will be used, with only minor changes. The version of the model considered here was initialized to 1970. Fix a DOE region, say region #1. In that region, in year t = 1970, 1971,...,1995, let

Q_t = total btu-content of oil used for space heating in old single-family homes

$E_{1970} = Q_{1970}/(HT_{1970} \cdot C_{1970})$: this initial value is an input to the model, and is in real units (btu's). It indicates the average amount of oil used for space-heating, by those old single-family homes which used oil for space-heating in 1970

HT_t = number of old single-family homes

C_t = fraction of old single-family homes which heat with oil

HS_t = average size of old single-family homes. This is an index, scaled to 1 in 1970

TI_t = average thermal inefficiency of shells of old single-family homes which heat with oil. This is an index, scaled to 1 in 1970. As TI gives up, so does energy consumption. Thus, TI is the inverse of an efficiency index.

EU_t = average inefficiency of oil-fired furnaces in old single-family houses. This is an index, scaled to 1 in 1970.

U_t = average usage of oil-fired furnaces in old single-family homes. Again, this is an index, scaled to 1 in 1970.

The Q-equation is

$$Q_t = E_{1970} \cdot HT_t \cdot C_t \cdot TI_t \cdot EU_t \cdot U_t \tag{1}$$

The factors C_t, TI_t and EU_t are updated by averaging their values in the preceding period with values for new and replacement housing and appliances in the current period, denoted CN_t, TIN_t, and EUN_t. The details are a bit obscure; in particular, the model does not seem to take into account the fact that when a house is scrapped, so is its shell and furnace. The difference in floor areas across housing types appears to be incorporated into the factor E_{1970}. The equation makes the implicit assumption that energy consumption is proportional to floor area; this assumption is open to serious question.

We now attempt a reconstruction of the thought process leading to the Q-equations, and discuss the problem caused by correlations among the factors. It is emphasized that the "reconstruction" is just that: the issues are not discussed in the documentation. As noted above, the model considers that energy consumption by a piece of equipment depends on its technological characteristics, its operating environment, and how it is used. For instance, the energy consumed by a refrigerator depends on technology (insulation, motor, self-defrost capability, etc.), and usage (thermostat setting, frequency with which the door is opened, etc.).

To focus on a specific example, fix some time period, and some category of refrigerators in households. For simplicity, suppose that each household has exactly one refrigerator. For each household in the category, let τ_i be a vector describing the technological characteristics of the refrigerator, and π_i a vector describing the usage pattern of the household. The first major assumption in the model seems to be that there is some function, call it f, which determines energy consumption by the refrigerator from τ_i and π_i; this is $f(\tau_i,\pi_i)$. Next, the total energy consumption by refrigerators in the category can be expressed as $N \cdot \bar{f}$, where

N = number of households in the category

$\bar{f}$ = average energy consumption by refrigerators in these households

This is a trivial piece of algebra, because

$$\bar{f} = \frac{1}{N} \sum_{i=1}^{N} f(\tau_1,\pi_i)$$

The sum is exactly the total energy consumption at issue.

This algebra is not helpful unless $\bar{f}$ can be computed. So the next idea is that f can be expressed as a product of three scalar numbers:

(2) $$f(\tau_i,\pi_i) = E \cdot EU_i \cdot U_i$$

where

E = the energy consumed by standard refrigerators under standard conditions

EU_i = an index of energy inefficiency for the particular refrigerator in household i

U_i = an index of usage by household i.

These indices are normalized to be one under "standard conditions," not defined in the documentation.

The concepts of "efficiency" and "usage" have much intuitive appeal, but they need careful definition for analytical purposes. Such definitions are not given in the documentation. Also the adequacy of the multiplicative relationship (2) is open to question. For example, some refrigerators may respond "efficiently" if the door is opened more frequently, but "inefficiently" if the thermostat is turned up. Other refrigerators may respond in the opposite way. If so, (2) may be inadequate. Again, this issue is ignored by the documentation.

In any case, formula (2) is not manageable, because it refers to individual households. So the next move is to replace EU_i and U_i by their averages over the category in question. That is, the model assumes

$$\frac{1}{N} \sum_{i=1}^{N} E \cdot EU_i \cdot U_i = E \cdot \overline{EU} \cdot \bar{U} \tag{3}$$

where

$\overline{EU}$ = average inefficiency index = $\frac{1}{N} \sum_{i=1}^{N} EU_i$

$\bar{U}$ = average usage index = $\frac{1}{N} \sum_{i=1}^{N} U_i$

However, equation (3) is not an identity but only an approximation. The average of products will usually differ from the product of the averages, due to statistical dependence among the factors. The documentation does not discuss the adequacy of the approximation in (3), or mention the issue of dependence among the factors.

The impact of this error on the forecasts is difficult to assess without rebuilding the model. It may therefore be worthwhile to indicate exactly where (3) breaks down, and this is easiest to do in a context which is largely hypothetical. Standard economic theory suggests that inefficient refrigerators may be used less heavily than efficient ones: the cost of using them is higher. let us assume this, for illustrative purposes. Then EU_i should be negatively correlated with U_i across households i. Under these circumstances, energy consumption will be less than predicted by (3):

$$\frac{1}{N} \sum_{i=1}^{N} E \cdot EU_i \cdot U_i < E \cdot \overline{EU} \cdot \bar{U} \tag{4}$$

Equation (4) is a theorem.[1] It is an assertion about the logic of the model, not about data. The point is to illustrate the problem in the model's accounting framework. For refrigerators, the effect is undoubtedly small. For space-heaters, it may be larger. One implication: when new and more efficient appliances are introduced, usage may go up too, which offsets some of the potential fuel-savings. This could be an important issue for energy policy analysis, and aggregation seems to blur the interaction between efficiency and usage, within the categories of the model. Interesting enough, the documentation stresses the fact that the model does reflect this interaction insofar as it occurs over time.[2] But the model fails to capture this interaction insofar as it occurs across households within a given time period.

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[1]To be perfectly definite: the assumptions are that EU_i and U_i show some variance across households i, and negative correlation.

[2]ORNL/CON-24, p. 35. **This is an Oak Ridge documentation report: see part 1 of the bibliography.**

4. The efficiencies submodel

The inefficiency indices for new equipment and new structures, as well as indices of equipment prices, are determined by a submodel which incorporates both economic and technological considerations. The key assumption: when making decisions about the purchase of new equipment or a new structure, consumers look at the life-cycle cost of each of the alternatives. This cost is simply the sum of the capital cost (i.e., equipment or structure price) and the discounted present value of future operating costs. Future operating costs depend, in part, on the technological characteristics of the equipment or structure. But efficient equipment and structures cost more than inefficient ones, so there is a trade-off between present capital costs and future operating costs. If there exists a spectrum of possible characteristics, there will generally be an efficiency level for a piece of equipment for a given end use which minimizes life-cycle cost. The actual efficiency of newly produced equipment and structures should be close to this minimum cost level, although the model does permit some departure from this level because of market imperfections. The model assumes that equipment inefficiency is constant over its lifetime; and that consumers buying appliances in year t will expect fuel prices to remain at their year t level forever.

To pursue the efficiencies submodel in more detail, a specific example will be helpful: gas water-heaters. The model seems to visualize a "standard" 1970 gas water-heater, which costs C_0, and uses E_0 btu's of energy annually, under "standard" operating conditions. The next construct in the model is a "technology curve," to be denoted here by ϕ. A consumer who is willing to pay the amount C_t in year t get a gas water-heater with energy inefficiency index $\phi(C_t/C_0)$, whose annual energy consumption in btu's is therefore

$$E_0 \cdot \phi(C_t/C_0) \tag{5}$$

In this equation, ϕ is the same for all housing types and states. A more important assumption is that ϕ is constant over time: there is no change in the trade-off between the capital cost of new equipment and its operating cost. This assumption is not discussed in the documentation, and does not seem to accord with experience. The model does allow exogenous upper limits to be set on fuel inefficiencies, to reflect mandatory standards. It may be just as reasonable to assume, however, that the standards will operate to change the trade-off: e.g., manufacturers might invest in developing new technologies.

The functional form specified for ϕ is as follows:

$$\phi(x) = D + \left(\frac{B+1}{B+x}\right)^A (1-D) \quad , \quad \text{where} \quad x = C_t/C_0 \tag{6}$$

Here, A, B, and D are parameters; D is an assumed lower limit on the inefficiency index. The implicit constraints are: $A > 0$ and $B > -1$ and $0 < D < 1$. The argument given for this functional form is only that it satisfies the law of diminishing marginal returns: $\phi' < 0$ and $\phi'' > 0$. In fact, however, ϕ does not satisfy these conditions.[1]

[1] To make the forecasts published in [30], the EIA chose B = -.99. If by mischance C fell to $.99C_0$ for lighting, the program would blow up. Below $.99C_0$, the curve is undefined or has the wrong shape. Is it unthinkable that constant dollar prices for lighting systems might fall 1%? There is a similar difficulty for 10 other appliances with negative B's.

Before going on to discuss the life cycle cost minimization algorithm, we pause to consider the parameters in (6). The documentation suggests that the parameters were adjusted by judgement or trial-and-error to fit engineering data. However, the data involved are themselves somewhat questionable. For instance, take the water-heater technology curves: the "data" are themselves outputs from a simulation model, this time one which describes water-heaters.[1]

Returning now to the life cycle cost minimization algorithm, details are not specified in the documentation; we will describe the procedure which is suggested there, indicating the problems. Granting (5) and (6), suppose that a consumer in year t, in some DOE region, is contemplating the purchase of a gas water-heater. The current price of gas in this region is X_t^g (in dollars per btu), and the consumer is assumed to expect this price to be stable. So the expected annual operating cost is[2]

(7) $$E_0 \cdot \phi(C/C_0) \cdot X_t^g$$

Discounted to the present, this is

(8) $$F \cdot E_0 \cdot \phi(C/C_0) \cdot X_t^g$$

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[1] ORNL/CON-24, pp 18-21.

[2] In principle, (7) should be multiplied by the usage factor U.

where[1]

(9) $$F = \frac{1}{r}\{1 - \frac{1}{(1+r)^T}\}$$

T = typical lifetime

r = interest rate

The parameters T and r are input by the user. It is an important assumption that T does not depend on the fuel, or on prices, and is constant over the forecast period.

The present value of the life cycle cost is

(10) $$C_t + [F \cdot E_0\ \phi(C_t/C_0) \cdot X_t^g]$$

A rational consumer with perfect information, as envisioned by the model, will seek to minimize this. Differentiate with respect to C_t and set the derivative equal to 0:

(11) $$\phi'(C_t C_0) = -C_0/(F \cdot E_0 \cdot X_t^g)$$

This equation determines C_t, and the inefficiency $\phi(C_t/C_0)$. With a perfect market, $\phi(C_t/C_0)$ would be taken for the inefficiency index EUN, and C_t/C_0 for the equipment price index PEQ. (This is needed in the CN-equations, section 5 below.) However, the model seeks to capture market imperfections by using what the documentation calls a "market penetration algorithm."

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[1] The documentation does not specify the discounting scheme. Apparently, the model uses F, but this is inconsistent with the assumptions made elsewhere in the model: geometric decay rather than sudden death at Time T. Also, the "half-lives" in table 10 on p. 34 of ORNL/CON-24 are incorrectly identified as "average lifetimes."

In effect, the model assumes that the discrepancy between actual and optimal in any year t will equal the 1970 discrepancy multiplied by a factor that depends on the ratio of fuel price in year t to fuel price in 1970. This device may produce reasonable results when fuel prices are steadily rising, but it will give strange predictions when prices fluctuate. If fuel prices rise sharply, the model assumes that efficiency of new equipment rises toward (but does not reach) the new optimal level. If fuel prices then drop, so does the optimum level. Consumers who have been buying very efficient equipment now revert to quite suboptimal levels. A more natural market penetration model would be explicitly dynamic: the discrepancy between actual and optimal would be treated as a function of the rate of change of fuel prices.

This completes the discussion for gas water-heaters; other appliances are treated the same way, except space-heaters and air-conditioners. The novelty here is that, following the logic used elsewhere in the model, formula (7) no longer gives the annual operating cost; it must be multiplied by housing size and the thermal index of the shell. In other words, the space-heater has to be installed in a house, to see how much it will cost to run. The documentation does not say how the characteristics of this house are determined.

Turn now to TIN, the thermal inefficiency of the shell for new structures. Here, there are some minor puzzles:

- There is one TIN for space-heating and one for air-conditioning. Apparently, this was done to reflect the empirical fact that insulation has different effects on space-heating and air-conditioning. However, a consumer must select only one shell for the house, not two: so the logic of the model is inconsistent here.

- There are separate "technology curves" for the thermal inefficiency of the shell, one for each fuel. Apparently, this was done to reflect the empirical fact that houses with electric space-heating are better insulated than houses with other kinds of space-heating. Again, however, there is only one shell, and it is distinct from the space-heating system. By the logic used elsewhere in the model, there should be only one technology curve for shells; a consumer who chooses electric space-heating might choose a different point on the curve, by the optimization procedure described above. These separate technology curves are inconsistent with the logic of the model.
- The technology curve for appliances is specified in terms of relative capital cost (C/C_0). For the shell, the argument is marginal capital cost ($C-C_0$). Thus C_0 affects the optimum cost for appliances through equation (11). Similar algebra shows that C_0 will not affect the optimum marginal cost for shells. Another inconsistency.
- There are two discount rates, one for all appliances and one for all shells. Why two, rather than one or eight?

There is also a major puzzle, noted above for space conditioning. The annual operating cost for space conditioning depends on the efficiency of the shell, as well as the efficiency of the furnace and air-conditioner, as well as housing-size and usage. How is this simultaneity to be resolved? For the rational consumer envisioned by the model, choice of fuel, appliance efficiency, shell efficiency, and level of usage all go together. This is a joint decision-making problem. Indeed, there is even some interaction across end-use: the space-heater, air-conditioner and shell have to be decided together. The model artificially splits the problem up into components, to make it manageable. The treatment is clever, but it may miss a lot: see McFadden (1981) for sample calculations. The documentation says nothing about why this simplification is considered reasonable.

There is another serious objection that can be raised to the way in which the efficiencies submodel integrates economic and technological considerations. According to the logic of the model, consumers inherit a fully equipped housing stock in 1970 and make changes only when growth in the number of households requires expansion or some part of the old stock dies. The typical lifetime of capital, the T of equation (9), is treated as a technological constant independent of price. For modeling the response to small changes in relative prices, this may be a plausible simplifying assumption. But it is a poor way to model the response to more substantial price changes. After all, the lifetime of capital equipment is as much an economic phenomenon as a technological one. If energy prices stay low, the consumer can afford to make do with the old energy-intensive equipment. But, when substantial price increases take place and are perceived as permanent, the consumer will be quicker to replace the old equipment with new to economize on energy consumption.

In the past, economies have adjusted to major price shifts by inventing entirely new ways of doing things. This means new technologies, different life styles (the move to warmer climates), changes in values (heated swimming pools become less a status symbol), and restructuring of economic institutions. Even property rights will change as externalities which become more expensive are internalized. The model does not envision the possibility of these structural changes, and admits new technology only through movement along the technology curves expressed by equation (5).

We think the engineering submodels are much too rigid. The net result is that the model as a whole is likely to be overly pessimistic about the public's ability to respond to changes in the price of energy. The long-run price elasticities may be seriously underestimated.

5. The CN-equations

Consider the new single-family housing units built in period t. For each end-use, a fuel must be chosen, e.g., space-heating can be accomplished with electricity, natural gas, oil, or "other/none." (The latter possibility includes other fuels such as liquid gas, as well as the option of no fuel at all, i.e., no space heating.) A similar choice is faced in an old single-family housing unit, whose space-heater has just burned out. Likewise for the other end-uses, and the other housing types.

A logit-type equation is used to predict the "market-shares," or fractions choosing the various fuels. The choice is related to operating costs, capital costs, and income. We will present the equation first, then comment on the issues.

Affixes

Affixes i = 1,2,3,4 and j = 1,2,3 are used for fuels:

1 is electricity	3 is oil
2 is natural gas	4 is other/none

The affix k is for end-use, t for the time period. Housing type is referenced by h, and state by m:

values of h	values of m
single-family	old
multi-family	new
mobile	

Equations

The equations are as follows:

$$(12)\quad \log \frac{CN_t^{ikhm}}{1 - CN_t^{jkhm}} = A^{ikhm} + \sum_{j=1}^{3} B^{ijk} \cdot X_t^j \cdot EUN_t^{jkh} \cdot TI_t^{jkhm} + \sum_{j=1}^{3} C^{ijk} \cdot PEQ_t^{jkh} + D^{ik} \cdot Y_t$$

There is a complete set of equations like this for each of the 10 DOE regions. Coefficients and variables are all region-specific. We define the variables next, and then comment on the coefficients. Fix one DOE region, and time period t.

Variables

CN_t^{ikhm} is the fraction of housing units of type h and state m which choose fuel i for end use k, in period t and the given region. When m = old, the model is dealing with replacements for burnt-out equipment. When m = new, the model is equipping new housing units.

X_t^j is the price of fuel j in period t in the given region.

EUN_t^{jkh} is the index of fuel inefficiency of new equipment in period t and the given region, burning fuel j for end-use k, and designed for installation in housing units of type h. For space-heating and air-conditioning, EUN depends on housing-type; for other end-uses, EUN does not in fact depend on housing-type. EUN is determined by the efficiencies submodel, section 4 above.

TI_t^{jkhm} is set equal to one, except for the end-uses space-heating and air conditioning. TI_t^{jkhm} represents the thermal inefficiency of the shell of a housing unit of type h and state m in period t and the given region, burning fuel j for end-use k. When m = new, the model is equipping new units; then, $TI_t^{jkhm} = TIN_t^{jkh}$ as determined in the efficiencies submodel. When m = old, the model is replacing burnt-out equipment; then TI_t^{jkhm} is the average index over the relevant housing stock.

PEQ_t^{jkh} is the cost in period t and the given region of equipment burning fuel j for end-use k, and designed for installation in housings units of type h. This does not depend on m: new and replacement equipment costs the same. PEQ does depend on housing-type. Also, PEQ is an index, scaled to 1 in 1970. Like EUN and TIN, PEQ is determined in the efficiencies submodel.

Y_t is per-capita disposable personal income, in period t in the given DOE region.

Coefficients

The intercept A^{ikhm} depends on the housing-type h and the housing-state m. This intercept is determined from assumed CN values for 1970. These are not specified separately by housing-type; the model assumes that the ratios across housing types will equal the corresponding ratios of fuel shares specified for existing housing. Separate matrices are input for new and replacement equipment. The other coefficients do not depend on housing-type or housing-state.

Most of the documentation is couched in terms of elasticities, and it is asserted that the B-coefficients in (12) come from elasticities developed earlier. The C-coefficients in (12) are derived from the B-coefficients via a set of "interest rates," to be discussed below. To run the model, elasticities and interest rates must be specified, not coefficients. However, the equation (12) does not have constant elasticities: the relationship between coefficients and elasticities varies from point to point on the curve. Thus, the documentation does not say what any of the coefficients in the equation really are, or how they were determined. Apparently, the elasticities are converted to coefficients at the point on the curve corresponding to 1970. We wonder whether equation (12) with its constant coefficients is the real behavioral model—or whether the modelers have some more basic model with constant elasticities to which (12) is only an approximation.

The documentation implies that the elasticities and interest rates used for the CN-equations are derived from cross-sectional regressions run on 1970 state-level Census data, as described in ORNL/CON-3, and are to that extent based on empirical evidence. This is the most elaborate statistical argument in the documentation. But it is not at all clear how ORNL/CON-3 can be the source of the estimates used in ORNL/CON-24.

- The elasticities reported on p. 17 of ORNL/CON-3 do not match those on p. 30 of ORNL/CON-24.
- Suppose the CN-equations on p. 47 of ORNL/CON-24 are the behavioral model. These apply to consumer choices of new or replacement equipment. The 1970 Census data apply to all equipment—new, replacement, and old. Cross-sectional regressions run on the 1970 Census data are therefore likely to give biased estimates of the coefficients.
- ORNL/CON-3 uses state-level data; the conclusions are applied to DOE regions.
- The equations in ORNL/CON-3 include weather variables and demographic variables missing in ORNL/CON-24. This too may bias the forecasts.
- ORNL/CON-3 omits altogether three of the end-uses considered in ORNL/CON-24; refrigeration, lighting, "other."

Finally, some comments on ORNL/CON-3 itself.

- The procedure used to derive the coefficients for equipment prices is surprising: over 1000 regressions were tried, before one was selected.
- The underlying behavorial model, if any, must apply to consumers not states; but the regressions are run on state-level data.
- The price data are synthetic and unreliable.

We return now to the logic of (12). These equations assume that consumers make independent fuel choices across end uses, which seems wrong: houses with gas furnaces are more likely to have gas water heaters as well. The equations also assume independent fuel choices across time, which seems equally wrong: home-owners replacing a gas water heater are likely to choose another gas water heater.

The main trouble with (12), however, is that there is no underlying model of consumer behavior to tie the calculations together. The logic of (12) is discussed in the auxiliary document ORNL/CON-3. There, it is suggested that (12) is related to the logit model discussed by McFadden (1974). The relationship is tenuous; in McFadden's model, the appropriate left-hand side variable is quite different, namely,

$$\log(CN_t^{ikhm}/CN_t^{jkhm})$$

And even his model is considered inappropriate for situations where there are many close substitutes—such as fuel choices. On this score, see Debreu (1960), or Tversky (1972), or even p. 113 of McFadden (1974).

The documentation does not present any explicit behavioral micro-model (e.g., utility-maximizing consumers with budget constraints) which leads to the specification. And the implicit theory is quite strange. Consider, for instance, the choice of fuel for space-heating in new single-family houses. This seems to be considered as a series of four separate decisions:

yes/no on electricity	yes/no on oil
yes/no on natural gas	yes/on no "other/none"

Take each in turn. To decide yes or no on electricity, the consumer seems to be modeled as computing the life-cycle cost of heating with each of the three major fuels—using a separate interest rate r for each. This requires three separate interest rates, which may be denoted as follows:

$$r^{\text{space heat}}_{\text{electric, electric}} \qquad r^{\text{space heat}}_{\text{electric, gas}} \qquad r^{\text{space heat}}_{\text{electric, oil}}$$

Moving on to gas, the consumer uses three more interest rates:

$$r^{\text{space heat}}_{\text{gas, electric}} \qquad r^{\text{space heat}}_{\text{gas, gas}} \qquad r^{\text{space heat}}_{\text{gas, oil}}$$

And the decision on oil takes still another triad:

$$r^{\text{space heat}}_{\text{oil, electric}} \qquad r^{\text{space heat}}_{\text{oil, gas}} \qquad r^{\text{space heat}}_{\text{oil, oil}}$$

The fourth decision ("other/none") is modeled inconsistently, as noted above, and brings on no new interest rates. So far, the model has nine interest rates, with more to come for the other end-uses: all in all, there are 72 possible interest rates for the CN equations, i.e., to model the consumer choice of fuels for various end-uses.[1] And when it comes to modeling consumer choice of appliance efficiencies (in the efficiencies submodel), still another pair of interest rates come in to do the present-value computations and the capital-cost/operating-cost trade-offs.

The "derivation" of the interest rate matrix does not make much sense.[2] Absent utility-maximizing consumers, there seems to be no justification for interpreting certain partial derivatives as "interest rates,"

[1] Of these, 41 are zero: since e.g. there are no oil-fired stoves, the corresponding B's and C's and interest rates are set to zero.

[2] ORNL/CON-3, pp 19ff

or using these numbers in present-value calculations. And we cannot imagine any consumer behavior which involves so many interest rates. The documentation urges the view that consumers in new housing units face a different capital market from those in old housing units—mortgage rates vs. consumer finance rates.[1] But the model seems to use the same set of interest rates for consumers in both new and old housing, so that is not the source of the multiplicity.

At the most, it seems reasonable to admit a different interest rate for each fuel and end-use: the gas-furnace dealer has a different finance plan from the oil-furnace dealer, and the terms for base-board heaters are different from either. Even this is far-fetched, and it only gives three interest rates for space-heating, not the nine used by the model. The plethora of model interest rates is very perplexing.

[1]ORNL/CON-3, p. 23; ORNL/CON-24, p. 48

6. The U-equations

In the model, usage of a piece of equipment varies over time in response to economic conditions. Usage is related to operating costs and incomes, in logit-like equations. We present the equations first, and then comment on the issues. The affix i will be used for fuel-type,[1] and k for end-use; h refers to housing type, and m to state. The equations are as follows:

$$(13)\quad \log\left(\frac{U_t^{ikhm} - 0.5}{1.5 - U_t^{ikhm}}\right) = E^{ik} + F^{ik} \cdot \log(X_t^i \cdot EU_t^{ikhm} \cdot TI_t^{ikhm}) + G^{ik} \cdot \log Y_t + H^{ik} \cdot \log\left(\frac{U_{t-1}^{ikhm} - 0.5}{1.5 - U_{t-1}^{ikhm}}\right)$$

There is a complete set of equations like this for each of the 10 DOE regions. Coefficients and variables are all region-specific. Variables are all as defined for the CN-equations in section 5, except

U_t^{ikhm} is the rate at which consumers use appliances burning fuel i for end-use k, in housing units of type h and state m, in period t and the given region.

$EU_t^{ikhm} = EUN_t^{ikh}$ when m = new

$EU_t^{ikhm} = EU_t^{ikh}$ when m = old; this is an average index of fuel inefficiency.

[1] When i = "other/none," apparently U is set identically equal to one, although the documentation does not say.

Coefficients

The coefficient H^{ik} of the lag term is set equal to 0.5, an arbitrary choice. The coefficients F^{ik} and G^{ik} are alleged to come from "usage elasticities," and when the model is run, such elasticities must be specified. However, equation (13) does not have constant elasticities, just as the CN-equation did not. Apparently, elasticities were converted to coefficients at the point on the curve corresponding to 1970. However, the documentation does not really say how F and G were determined, or what their values are. The assumed elasticities for the U-equations result from "...engineering possibilities and our judgment."[1]

The situation is even more confusing with respect to the intercept E^{ik} in (13). The idea seems to be that $U^{ik}_{1970} = 1$, so E^{ik} can be determined if e.g., U^{ik}_{1969} is specified. However, this information is supplied only for three fuels, not 3 fuels and 8 end-uses.

We will mention three minor issues:

- The fuel "other/none" is handled in an unsymmetric way.
- On the right-hand side of the equation, X • EU • TI seems to represent an operating cost, or the marginal cost of an extra unit of utilization. For space-heating and air-conditioning, floor area HS should come in.
- When a consumer in an old housing unit is trying to figure out how high to set the thermostat, average thermal inefficiencies of shells and average energy inefficiencies of furnaces are irrelevant; it is the consumer's own shell and furnace that count. Likewise for income. These are aggregation errors. Aggregation

[1] ORNL/CON-24, p. 31

errors of this sort appear throughout the model.

The major issue, however, is that the functional form is arbitrary and unmotivated. The idea of usage being related to operating costs and incomes may be plausible at the level of individual consumers; the model applies this idea to aggregate data in quite a mechanical way. Of course, "the intensity with which household equipment is used," to quote ORNL/CON-24, is a very appealing idea. But it might be quite hard to define and measure. Indeed, the treatment of usage in the model is almost completely *a priori*, and free of data.

7. The housing submodel

The model requires as input data forecasts of the number of housing units, broken down by type (single-family, multi-family, mobile home), state (new, old) and region. It also requires an index of average housing-unit size for each category. These forecasts are made by an exogenous housing submodel which takes as input demographic projections made by the Bureau of the Census, and the Gross National Product (GNP) projections made by Data Resources, Incorporated.

The submodel divides the national adult population into seven age groups. For each group the headship rate (fraction of people in the group who are head of a household) is predicted from a logit-type equation. The explanatory variables are median family income for the age group, the fraction of the group married and living with their spouse, and the fraction of the group who are separated or divorced. The equations were fitted to national census data for the period 1952-1976. The total number of households is obtained by multiplying projected population in each age group by the predicted headship rate and summing. This procedure requires forecasts of median family income and marital status fractions for each age group. We do not think such forecasts are available and hence are not at all sure how the submodel actually predicts the number of households.

The predicted households are assigned to regions by using forecast regional shares of the population. The households in each region are shared among the housing types by extrapolating the 1970 shares. This sharing is apparently done separately for each age group, although it is not clear whether the age distribution has been estimated separately for each region. In this way the number of occupied housing units of each type in each region is determined. Existing housing units are retired at a constant rate. This rate depends only on housing type: it is constant over all regions and does not respond to changing energy prices. It does not depend on floor area, thermal inefficiency, etc. New construction is calculated as the sum of retirements plus household growth.

Because of data limitations, only one housing-size equation—for new single-family houses—was fitted. We are not sure what equation is used for new multi-family units and mobile homes; perhaps their size was assumed to grow at the same rate as for new single-family houses. The equation for new single-family houses predicts housing size from forecasts of median family income, average price (per square foot) of new homes, and average household size. There is one national equation with separate regional intercepts. The documentation does not indicate where the input forecasts come from, especially of prices. Apparently, average houshold size is calculated from outputs of the headship equation.

The housing submodel is exogenous to the energy sector. The distribution of people over regions and housing types and the choice of housing size determine energy demand; but energy price has no feedback effect. This strong assumption is not discussed explicitly in the documentation. The contrary view is just as plausible: as energy gets more expensive, people may well decide to live in central cities rather than suburbs, in warm climates rather than cold, in apartments rather than houses. If so, the model forecasts are biased. Of course, the long-run population forecasts and housing-type extrapolations could be adjusted to incorporate these effects, and mitigate the bias. But then an important factor in the price elasticity of energy use would be removed from the formal model and estimated subjectively.

8. Statistical issues

By running the computer code, analysts get definite, numerical answers to policy questions. That is why models are so attractive. The hope must be that the actual economic agents, the households and the firms, will behave more or less the way the computer code suggests they will. Is this hope well founded? To what extent is the economy like the computer code? These are the crucial questions to ask about a policy model, and there are two basic ways to answer such questions: by theory, and by history.

The "theory" approach is to show, by some *a priori* argument, that the model is a faithful representation of the essential features of the economy. In the present instance, such an argument is hard to make. Although the overall design of the model does embody some useful general ideas about the structure of energy markets, the transition from qualitative insights to quantitative analysis is much less satisfactory. Economists simply do not have well-developed theory governing the detailed structure of energy markets. As a result, the modelers were forced to make countless arbitrary decisions. The inconsistencies noted above may well be due to the need to resolve difficult questions without adequate theory. Finally, even if the detailed theory existed, there just is not enough data to estimate the parameters.

The "history" argument is that, whatever its theoretical merits, the model has in fact predicted well in the past, so its future predictions should be trusted. To some extent, the force of this answer will depend on whether the predictions are made *ex post*, i.e., after the fact, or *ex ante*, before the fact. *Ex ante* predictions are more persuasive than ones made *ex post*, because a model can always be fine-tuned to reproduce the past. However, we do not know of any systematic study of ex ante predictions by the model. Indeed, the time horizon of the forecasts is so long, and the model is developing so rapidly, that such studies would be very hard to do.

That leaves predictions ex post. And Hirst seems to rest his argument for the validity of the model on its ability to reproduce the past: see ORNL/CON-24 or Hirst (1978). However, this argument is quite weak, essentially for statistical reasons. A national version of the model will have upwards of 750 possible parameters, which must be specified to the model before it runs.[1] In ORNL/CON-24 and in Hirst (1978), the forecasts are checked against outcomes only for about 100 numbers. These outcomes include, e.g., the 1975 numbers for

- total residential use of electricity
- the fraction of homes heating with natural gas
- the fraction of residential energy consumption going into water-heating

Thus, the parameters in the model substantially outnumber the predictions.[2]

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[1]By parameter, we mean not only slopes and intercepts, but any number in the model which describes past or present behavior. We do not count forecasted values of exogenous variables as parameters. About 300 of the 750 parameters are set equal to zero. Another 50 or so can be derived from that fact that shares sum to unity. The parameters include such pieces of information as the average lieftime of an oil furnace, its average price in 1970, the average amount of energy consumed by such furnases in 1970, and the fraction of single-family homes which heated with oil in 1970.

[2]The model was originally developed at the national level. However, the version in use at EIA is regional. In effect, there are 10 copies of the model, one for each region. These use structurally identical equations, but with different parameters. The first impression of 7500 parameters, may be excessive: about one-third of the parameters are constant across regions, two-thirds are region-specific.

In short, however well the model may reproduce the past, this offers little hope for the future. In fact, the model does not reproduce the past so well, as will be seen in section 10.

9. A track record study

We did a small track-record study of our own, on the regional version of the model, for predictions *ex post*. Due to data problems, the results must be interpreted with caution, but they may be interesting. Some preliminary remarks on method are in order. To evaluate predictions, a reference point is helpful, so that accuracy can be measured relative to something. We use the conventional reference point of "persistence" forecasting. Too, some data base is needed. We chose the Federal Energy Data System (FEDS), on the grounds that we had it [27]. (The Hirst-Carney data base does not seem to be readily available.) The accuracy of FEDS may be an important point, and more about this below; also see [15]. But for the moment, take the FEDS numbers as "the truth." We chose to consider forecasts with a five-year time horizon. The version of the model under review is initialized to 1970; so consider the problem of predicting the 1975 FEDS numbers from some 1970 numbers, by two methods, both *ex post*, being done in 1980.

Method I. Persistence forecasting. Use the 1970 FEDS numbers as the predictions, with absolutely no changes or adjustments. For example, take residential consumption of distillate oil in DOE region #1. In 1970, this was reported by FEDS as 390 trillion btu. So method I predicts 390 for 1975. The value reported by FEDS[1] for 1975 was 360: method I makes an error of 30. See the columns headed "FEDS 70" and "FEDS 75" in table 1. Of course, method I is not a very sensible method. It ignores the embargo, the run-up in fuel prices, population changes,

[1] Synergy (19796, p. 56); the entries are 390,004 and 359,685; we rounded them.

Table 1. The Model vs Persistence Forecasting, FEDS data.
Base year is 1970, target year is 1975. Units are trillions of btu's.

region	electricity			natural gas			distillate oil			liquid gas		
	Model	FEDS 70	FEDS 75	Model	FEDS 70	FEDS 75	Model	FEDS 70	FEDS 75	Model	FEDS 70	FEDS 75
1	86	71	90	147	135	145	405	390	360	36	13	16
2	146	127	148	511	502	471	634	613	556	37	15	17
3	230	158	205	513	515	477	312	293	270	50	21	24
4	455	345	458	391	386	364	185	118	92	243	129	118
5	384	299	385	1720	1656	1691	609	463	455	307	150	159
6	261	168	239	543	502	500	46	0.86*	1.18*	199	138	109
7	107	84	111	396	421	415	68	58	50	191	104	102
8	51	34	49	211	198	225	27	33	30	73	38	36
9	192	143	187	597	608	702	24	7*	7*	36	30	17
10	119	97	129	68	68	90	64	73	51	13	12	7
average absolute error	8	48		34	29		56	22		58	8	

*These are not transcription errors on our part. We do not know why the FEDS numbers are so small; the ones for region 6 must be wrong--that includes Texas! These cells were excluded from the averages.

etc., etc. It is used only as a reference point.

Method II. The model. Method II uses a sample computer run for the EIA/DOE 1979 Annual Report to Congress [30]. This *ex post* forecast of 1975 was produced in 1980, by a model which was initialized to 1970. (The model runs out to the year 1995, and predicts every year from 1975 onwards.) Many inputs, like the intercepts of the CN- and U-equations, seem to have been fine-tuned to make the model track well in the mid 1970s.[1] So this 1975 forecast is truly *ex post*: it uses information which was not available in 1970. The 1975 forecasts from the model are shown in the column headed "Model." in table 1.

Comparison. Average absolute errors are shown along the bottom of table 1. The model does relatively well on electricity, but fares poorly on natural gas and distillate oil. On liquid gas, the model is very far out of line. We see two alternative explanations for the results:

- in detail, for some fuels, the model is inferior to persistence forecasting;
- the model and FEDS have different concepts of the residential sector, distillate oil, etc.; different procedures were used to synthesize the two data bases.[2]

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[1] Also, apparently, the control price and income elasticies were derived from FEDS via RDFOR, and reflect the experience of the period 1960-78.

[2] On the definitions and initialization, see Borg et al. (1978). On the procedures used to synthesize the data bases, see Herbert (1980) and Freedman-Rothenberg-Sutch (1980). While different in detail, overall the procedures were remarkably similar. As we understand the Borg memo, the EIA version of the model was reinitialized to make it compatible with FEDS; and the "other/none" fuel category was initialized as liquid gas. If so, that speaks for our first interpretation of table 1.

Even the second interpretation is not so good for the model. Suppose the discrepancies in table 1 do result from differences in definitions and in the data estimation procedures. What this means is that knowledge of the past, at the level of detail required by the model is quite shaky. Surely this uncertainty must be greatly magnified in extrapolation.

The view may be advanced that predictions in detail do not matter, only the aggregates count. Perhaps so. But the aggregates vary quite smoothly over time, and naive statistical time-series methods, with only a handful of parameters, will track the aggregates from 1960 to 1980 just as well as the model, or even better. Would analysts trust such curve-fitting methods to extrapolate to the year 1995 on the basis that they fit over the period 1960-80? We think not. And the *ex post* track record argument for the model seems to be even weaker.

10. The initialization to 1970

The data base for the model was reviewed by Herbert (1980), and found to be largely synthetic: the result of imputation, rather than measurement. These data, however, are not so relevant for the regional version of the model under review: indeed, most of the statistical estimates for parameters derived from the data are discarded and replaced by judgemental estimates. What is very relevant is the set of 1970 initial values supplied as inputs to the model. These will be reviewed here, and they too turn out to be largely synthetic. The number of initial values is so large that considering each in turn is not feasible; taking a statistical sample seems unnecessarily formal. We will use the old-fashioned anecdotal method, illustrating the conclusions by examples; we think this gives a fair picture of the situation.[1]

Example 1. Equipment prices. Equipment prices are assumed not to vary across DOE regions. For an electric space-heating system, in single-family homes, the assumed price is $1200. In multi-family units, the assumed price is $600, half as much. In mobile homes, the assumed price is $900, three-fourths as much. Exactly the same ratios apply to space-heating systems burning the other fuels. Almost the same ratios apply to air-conditioners. In short, the equipment prices are synthetic.

Example 2. Energy use. In 1970, in DOE region #2, in single-family homes, Table 2 shows the assumed annual average energy use for

[1] The source for these examples is an input file used for one of the "medium" forecasting runs in Volume III of the EIA/DOE 1979 Annual Report to Congress [30].

space-heating and air-conditioning with natural gas.

Table 2. Average energy use in 1970 in DOE region #2: natural gas. Units: millions of btu's.

	space-heating	air-conditioning
single-family	158.0311	24.7746
multi-family	64.7929	10.1576
mobile homes	96.3989	15.1125

"Average" means: per household, among those households using the indicated fuel for the indicated end-use. We have seen nothing to indicate how such numbers were arrived at. There is data showing total residential natural gas consumption in 1970 by DOE region 2. But it is not at all clear how to break this down by end-use and housing type. — The numbers in table 2 may well be reasonable ball-park guesses: but no empirical foundation has been laid for them.[1]

There is one interesting empirical fact about table 2: in both columns, the three numbers stand in the same ratios, viz.

as 1.0000 to 0.4100 to 0.6100

These exact ratios across housing types can be observed in the other fuels for these two end-uses, and in all ten DOE regions. In short, the energy use numbers are synthetic. These are the baseline factors for equation (1): uncertainty about them gets translated directly into uncertainty about the forecasts.

Example 3. Lights (a minor point). In every DOE region, the lighting system has an average lifetime of one year; with capital costs

[1] Such data are not available even from the Residential Energy Consumption Survey.

of \$22, \$15, and \$11 respectively for the three housing-types. What do these numbers cover, e.g., light-bulbs or fixtures? Too, half the housing units are lit by electricity, and half by the fuel "other," but "other"-burning lighting systems consume no energy. Is this candles, or what? This example illustrates the patchy quality of the input data.

Example 4. Gas-fired other-doing equipment (a minor point). This sort of equipment includes e.g. gas-fired clothes-dryers. Prices are shown for this sort of equipment, and some non-zero fraction of other-doing equipment was gas-fired: but this sort of equipment used no energy. Again, this example illustrates the inconsistencies in the model input files.

The credibility of model forecasts depends on many factors, including the logic of the equation and the quality of the parameter estimates. Even granting the logic, with the regional version of the model there are some 5000 parameter estimates. Their validity cannot be defended on statistical grounds, because they were derived not from any objective statistical procedure but from the judgment of the modelers, as our examples show. In essence, the only way to justify the parameter estimates is on the basis that the modelers have good judgement and know what they are doing. Surely this is an odd state of affairs. The usual argument in favor of modeling is that it is objective, and the assumptions have been made explicit. With the regional version of the model, there are 5000 subjective, implicit sets of assumptions to think about—the ones driving the parameter estimates. The validity of these assumptions, and their impact on the forecasts, is almost impossible to assess.

11. Conclusions

The overall conception of the model embodies many useful insights into the energy market. The translation into specific equations, however, is much less satisfactory. Many of the choices seem arbitrary, and there are many inconsistencies in the internal logic of the model. The model seems best suited for forecasting the response to small changes in relative prices (although its reliability in this regard has not been demonstrated in any rigorous way). The structure, however, must be considered as overly rigid for use in predicting long-run responses to large shifts in relative prices or to significant policy changes. Technical change, the geographical location of residential housing, and the rate of obsolescence are all insensitive to price changes within the model. As a result, the long-run price elasticities are likely to be seriously underestimated.

The parameters of the model have been estimated by procedures which are neither explicit nor objective. They are not derived from any well-defined data base by well-defined statistical procedures. Too, the parameters of the model outnumber the predictions. Furthermore, the forecasting horizon of the model is rather long, and its detailed structure seems to be under constant revision. For these reasons, realistic measures of uncertainty cannot be attached to the forecasts on the basis of statistical theory or track-record studies.

Some of the deficiencies in the model could be remedied by a reasonable application of resources: for example, it would be possible to disaggregate by vintage. However, it is open to question whether the reliability of the improved model could be demonstrated in any convincing way. Mid-term forecasts could be made in less detail; simpler and more robust forecasting techniques could be developed. Either time-series methods or small-scale econometric models could be considered. Clearly, such models would not be able to answer certain kinds of detailed questions. On the other hand, there is no evidence that the answers from the present models can be depended upon.

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