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Selected Comments on the ORNL Residential Energy-Use Model

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Abstract

Selected Comments on the ORNL Residential Energy Use Model

The purpose of these comments is to identify some questionable procedures employed in the Oak Ridge National Laboratory (ORNL) Residential Energy Use Model. The examples presented are illustrative of the type of analytic problems discovered in a detailed assessment of the model.

The purpose of these comments is to identify some critical technical aspects of the Oak Ridge National Laboratory (ORNL) Residential Energy Use Model recently reported on in Land Economics (Eric Hirst and Janet Carney 1979).

In published reports of the model (Hirst 1978(a), Hirst 1978(b)), there is much information on the level of detail at which the model either is constructed or can forecast. There is little discussion of technical issues. This is also true for the primary documentation (Hirst and Carney 1978; Cohn, Hirst, and Jackson 1977; Lin, Hirst and Cohn 1976; Hirst and Carney 1977) which tends to adumbrate technical aspects of the model rather than to present and analyze these aspects in detail.

The ORNL model and data series represent a major conceptual contribution to the quantitative measurement of residential energy market and engineering relationships. It also enables a quantitative response to many important policy questions. Yet, accurate answers are dependent on the logical integrity of the model, the statistical meaningfulness of estimated relationships, and the soundness of the primary data. These technical topics are addressed in the comments to follow.

An important component of the ORNL model is determination of the thermal performance of new equipment or structures. This component is discussed on pages 323 and 324 of the article.

The function that appears on page 324 is a result of the technologies submodel in which a convex curve¹ is fit to disparate points which relate energy efficiency improvements to increased capital cost. A point is determined on this function that minimizes the lifecycle cost of thermal improvements. Lifecycle cost is then increased by an amount (D) to determine the market as distinct from the optimal solution.² D is calculated by means of the following formula

$$D = D_o \cdot (P_o/P_t)^n \quad (1)$$

where $n \geq 0$

D_o = some base period lifecycle cost difference between the optimal and the market solution

P_o = some base period fuel price in real dollars

P_t = some fuel price at a later time period t

Since n is set equal to one the actual calculating formula is

$$D = D_o \cdot (P_o/P_t) \quad (2)$$

The final lifecycle cost solution obtained by performing this additional calculation is intended to capture the fact that consumers tend to spend less on equipment than is indicated by the

¹Diminishing marginal returns is used as justification for the convexity of this curve even though it is clear in their original graphs that for some additional improvements non-convexity obtains. This implies that some additional improvements might never be implemented. The authors tend to replace such empirical facts with informally introduced theoretical notions and thus possibly avoid careful analysis.

²An explicit step-by-step mathematical statement describing how solutions are obtained, oddly enough, is not to be found in any ORNL documentation.

minimization of lifecycle cost criterion using the market rate of interest, unless the price of an energy fuel increases dramatically. There are several problems with this procedure as presented.

First, the authors claim that they set n equal to one because of absent data on the appropriate value for n . However, in a report that they reference (Dole 1975), a function is presented which is equivalent to their relationship. This function is

$$D = D_0 \cdot (P_t/P_0)^{-n} \quad (3)$$

However, n is set equal to .33 in the Dole report. This result is never acknowledged, yet alone discussed. Second, the distance D is completely insensitive to the time dimension in that it makes no difference in the calculation of D whether a 50 percent change in P occurs over a 5- or a 10-year period. It still calculates the same value. Finally, there is a fundamental problem in obtaining data to determine the relationship between incremental capital cost and increased energy efficiency for equipment and structures that is representative of such relationships for the Nation as required by the modeling framework.

The Hirst/Carney market share (CN) relationship that appears on page 325 of their report also requires some comment. This relationship is estimated for fuel i in end use k for m household types.

$$\ln(CN_t^{ikm}/1-CN_t^{ikm}) = a^{ikm} + \sum_{j=1}^3 (B^{ijk} \cdot X_t^j \cdot EUN_t^{jkm} \cdot TI_t^{jkm}) + \sum_{j=1}^3 (C^{ijk} \cdot PEQ_t^{jkm}) + D^{ik} \cdot Y_t \quad (4)$$

where A,B,C,D = coefficients derived from market share elasticities.

X_t^j = fuel price j in time period t³

EUN_t^{jkm} = new equipment energy use of fuel j in end use k in housing type m.

TI_t^{jkm} = average thermal performance of fuel j in end use k in housing type m.

PEQ_t^{jkm} = new equipment purchase price that uses fuel j in end use k in housing type m.

Y_t = per capita income

t = time period

The coefficients in the above relationship are outputs of an ORNL algorithm called an elasticity estimator. The elasticity estimator readjusts market share elasticity estimates obtained from a study by Lin et.al. (Lin, Hirst, and Cohn 1976). The coefficients in the above equation are their readjusted estimates. The relationship from the Lin study that is the source of the market share elasticities is:

$$\ln(CN_t^{ik}/1-CN_t^{ik}) = a^{ik} + \sum_{j=1}^3 B^{ijk} \cdot X_t^j + \sum_{j=1}^3 C^{ijk} \cdot PEQ_t^j + D^{ik} \cdot Y_t + u_t^{ik} \quad (5)$$

The variables and coefficients in equations (4) and (5) are similar, but there are some obvious differences.

First, the B coefficients are originally estimated by regressing on a price variable (X). Surprisingly, another independent variable-operating cost (X·EUN·TI) is employed for forecasting.

³To assume a constant price of fuel for all end uses and housing types may not be justified.

Second, the intercept terms (a^{ik}) are redefined for the three housing types (a^{ikm}). It appears that the authors redefine results of a least-squares fit by ad hoc division in order to obtain results consistent with a desired level of detail.

Third, the fact that the coefficients in equation (4) are defined as market share elasticity estimates from the elasticity estimator creates a problem. In order for these estimates to be used in this way, a transformation is first required. If this transformation is not performed, they are inconsistent with their source-equation (5). Employing the results of equation (5), market share elasticities (E^{MS}) are computed by means of expressions such as the following:

$$E^{MS} = B^{ijk} \cdot X_t^j (1 - CN_t^{ik}) \quad (6)$$

Therefore, E^{MS} values from the elasticity estimator should, in principle, be divided by $X_t^j (1 - CN_t^{ik})$ or their mean values $\bar{X}^j (1 - \bar{CN}^{ik})$ to obtain the B coefficients that is

$$B^{ijk} = E^{MS} / X_t^j \cdot (1 - CN_t^{ik}) \quad (7)$$

The preceding comments apply to parts of the economics, technologies, and market penetration submodels of the ORNL residential sector model. The remaining submodel is the demographic submodel. A part of this submodel that is used to forecast an important input for their simulation model--the stock of occupied housing units or the number of households--is

next examined. Forecasted values for this variable are obtained as a result of calculating or estimating several relationships. These relationships are listed below.⁴

$$HR_{a,t} = \frac{HT_{a,t}}{POP_{a,t}} \quad (8)$$

where $HR_{a,t}$ = the headship rate for age group a in year t . This variable represents the proportion of the population in age category a in year t that are household heads.

$HT_{a,t}$ = number of households that are headed by individuals in age category a in year t .

$POP_{a,t}$ = size of population in age category a in year t .

$a = 1, \dots, 7$ age categories.

Forecasted values for $HR_{a,t}$ are obtained by the following equation

$$\ln\left(\frac{HR_{a,t}}{U_a - HR_{a,t}}\right) = A_a + \beta(1)_a \cdot Y_{a,t} + \beta(2)_a \cdot SD_{a,t} + \beta(3)_a \cdot M_{a,t} + \beta(4)_a \cdot Z_{a,t-1} \quad (9)$$

where U_a = some assumed upper limit for the headship rate in age group a .

$Y_{a,t}$ = median family income in constant dollars for families in age group a in year t .

$SD_{a,t}$ = the proportion of individuals who are separated or divorced in age group a in year t .

$M_{a,t}$ = the proportion of individuals who are married and living with their spouses.

$Z_{a,t-1} = \ln(HR_{a,t-1} / (U_a - HR_{a,t-1}))$

$A, \beta(i)$ = coefficients determined by least squares.

The authors claim that the national projection of households can be disaggregated for each of the nine Census or ten Federal

⁴ Parts of the following mathematical description are supplied by the present author. This is necessary since calculations are frequently only expressed in narrative form in ORNL documentation.

regions.⁵ The description in the ORNL documentation suggests that the following calculations are performed to obtain this level of detail. First, HT_t is formed by summing over all a for each t the product of the age specific population and headship rates, that is

$$HT_t = \sum_a (HR_{a,t} \times POP_{a,t}) \quad (11)$$

where HT_t = the national projection of households in year t .

Then, $HT_{r,t}$ is formed in the following manner

$$HT_{r,t} = HT_t \cdot \frac{POP_{r,t}}{POP_t} \quad (12)$$

where $HT_{r,t}$ = the number of households in the r th region.

The above procedures describe how regional forecasts are obtained. They are not obtained directly but are obtained by assuming that each region's share of the Nation's households corresponds to that region's share of the Nation's population. Therefore, regional forecasts are not obtained as a function of changes in the value of regional median income and other variables but rather as a function of changes in forecasted population at the regional level of detail. Moreover, regional forecasts are not required for their simulation model but rather National forecasts are required. These forecasts are required at the single-family, multi-family and mobile homes levels of detail. This level of detail is obtained by formulas such as:

$$HT_t \cdot F_{m,t} = HT_{m,t} \quad (3)$$

⁵This disaggregation, however, is not necessary to obtain the required inputs for their simulation model.

where $F_{m,t}$ = the fraction of households that
are of housing type m.

$m = 1, \dots, 3$ housing types

The authors state that F is able to be calculated at the age category level of detail. However, this level of detail is not required for their simulation model. Two sets of values for $F_{m,t}$ are obtained by assuming that:

1. The percentage of housing types remain constant at their 1970 values at the age category level of detail.
2. The changes in the percentage distribution of housing types that occurred between 1960-1970 continues linearly to the year 2000 at the age category level of detail.

Therefore, housing type choice is not expressed as a function of changes in economic and demographic variables but rather as an extrapolation of historically determined proportions. In conclusion, what appears to be a regional forecasting model is actually an aggregate national model that is regionalized by multiplying national forecasts by exogenous regional population forecasts. It is disaggregated further to housing type by multiplying these forecasts by constant factors over the forecasted time horizon. Therefore, household formation at the housing type/age category levels of detail is not determined as a function of regional variations in the magnitude of the variables affecting this choice.

The national model (equation 9) requires a few additional comments. Hirst and Carney state that "M is not used as an independent variable for the first five age groups and SD is not used for the last three." ⁶ Neither is used for age group 5. They also state that: "The coefficients for these terms in equations that included them had very low t-statistics. Their rejection can also be argued on demographic grounds." It is instructive to reexpress equation 9 to reflect these facts, that is:

$$Z_{a,t} = A_a + \beta(1)_a Y_{a,t} + \beta(4)_a \cdot Z_{a,t-1} \quad (14)$$

Equation (14) clearly reveals that forecasted increases in the headship rate (Z) are primarily a function of changes in median family income. Therefore, the complicated process of household formation over time is largely determined by aggregate median income,⁷ regional population forecasts and an assumption of constant growth in housing type at the age category level of detail.

The above comments point to merely a few of the problematic analytic issues involved in attempting to construct and use a multipurpose/multisource model such as that developed by ORNL. In summary, the moral of the above is: Use with care.

⁶See Reference 1, p. 9

⁷Rather than permanent income. See Ref. 9.

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