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SHORT-RUN RESIDENTIAL DEMAND FOR FUELS:
A DISAGGREGATED APPROACH

by

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I. Introduction

The demand for energy on the part of the residential sector is a derived demand given the demand for the services provided by that given energy source in conjunction with the capital used with that energy source. Any analysis of energy demand must deal with the fact that fuels and fuel burning appliances/equipment are combined in varying ways to produce a particular residential service. As a result, analysis of the demand for energy should include explicit analysis of the interactive demands for both fuel-burning capital and the fuel used by that capital stock.¹

To summarize this demand behavior,² three types of decisions on the part of the residential energy user are involved:

- 1) The residential consumer decision of whether to buy or replace a fuel-burning durable good, capable of providing a particular comfort service (e.g., cooking, heating, lighting, air conditioning, etc.).
- 2) The residential consumer decision about the technical and economic characteristics of the equipment purchased and its requisite fuel, and whether the equipment embodies a new technology.
- 3) Given such equipment and its technical characteristics, the decision about the frequency and intensity of use.

These three decisions span the short-run (when the appliance stock and characteristics are fixed) and the long-run (when the size and

¹The interactive character of these demands has evidenced both complementarity and substitutability. For some clarification of the issues involved with an industrial focus, see E. Berndt and D. Wood, "Engineering and Econometric Approaches to Industrial Energy Conservation and Capital Formation: A Reconciliation," forthcoming American Economic Review, September, 1979.

²For a more formal development, see Hartman [1979].

characteristics of appliance stock are variable). While it may be useful to think of the decisions as sequential, they are also clearly interactive. For example, the consumer choice regarding fuel type and equipment characteristics (2) can affect the consumer decision to hasten or postpone the durable purchase (1); thus, the presence of a new technology in the choice set could induce or retard both retirement of existing consumer durables and new purchases of consumer durables. Likewise, consumer decisions regarding fuel/equipment choice (2) may be tied to projected intensity of use (3). While such simultaneity may be important and is the subject of further ongoing research, this paper focuses on the third decision only and treats it as independent of the other two.

There already exists a wide array of residential energy demand models that have analyzed this third decision.¹ Many of these efforts are fairly aggregate;² many leave implicit the interactive character of appliance stock and fuel demands.³ Those studies which explicitly incorporate the appliance stock still treat it as an aggregate.⁴

This study deals explicitly with the interaction between appliances and fuel demand; the distinguishing characteristic of the model is that the appliance stock is disaggregated and demand is estimated for those disaggregated end-uses. Instead of aggregating different appliances into a single stock measure and estimating average price and income elasticities,⁴ demand

¹For a critical review of this literature see Hartman [1978].

²For example, Anderson [1972]; Balestra [1967]. Baughman and Joskow [1974]; Berndt and Watkins [1977]; Griffen [1974]; Halvorsen [1973]; Houthakker [1951]; Houthakker, Verleger and Sheehan [1974]; Mount, Chapman and Tyrrell [1973]; Taylor, Blattenberger and Verleger [1977]; and Wilson [1971].

³For example, Anderson [1972]; Balestra [1967]; Baughman and Joskow [1974]; Berndt and Watkins [1977]; Griffen [1974]; Halvorsen [1973]; Houthakker [1951]; Houthakker, Verleger and Sheehan [1974]; Mount, Chapman and Tyrrell [1973] and Wilson [1971].

⁴See Fisher and Kaysen [1962]; Acton, Mitchell and Mowill [1976]; Taylor, Blattenberger and Verleger [1977]; and Willis [1977].

is represented as the sum of separate demands for fuel for different appliances and price, income, and weather elasticities are allowed to differ among the different uses. Such disaggregated analysis of the capital stock characterizes frontier energy demand work; given the disaggregated demand elasticities, the analysis permits greater technological specificity to assess the effects of disaggregated appliance efficiency standards and new technologies.¹ The model incorporating this disaggregation for electricity and natural gas demand is introduced in Section I.²

As in many of the demand models, the data used here consists of annual observations for each state for the years 1960-1975.³ In addition to weighted least squares (WLS), the paper uses two data pooling techniques, the random effects and fixed effects models. Furthermore, a specification test is performed to test for the consistency of the random effects model estimates. We find in all cases that we must reject the hypothesis that the random effects model generates consistent parameter estimates. We feel the results of this test are very important since many demand models utilize the random effects model. The results of these estimates are examined in Section II.

Finally, Section III discusses the conclusions drawn from the short-run modeling efforts and relates the results to broader efforts of residential energy demand modeling.

¹For greater discussion, see Hartman [1979].

²For detailed discussion of the model, see Werth [1978].

³The more disaggregated the data, the better will be the behavioral models and their parameter estimates. For example, more detailed and refined analytic results and policy assessments are possible if the geographical units are utility areas, meter readbook areas, cities and SMSA's (such as found in the work of Acton, Mitchell, Mowell (1976) and Wills (1977)). However, the richest data sources are currently pooled state cross-sections of annual time series. These sources give the broadest variation across geography, climate, and socio-economic conditions.

I. The Model of Short-Run Demand

Although residential energy demand has been modeled by many researchers, only a few studies adequately differentiate short-run and long-run demand.¹ Since the primary distinction between the two as defined here is that the appliance stock is held constant in the short-run, a short-run demand model should explicitly incorporate the stock of appliances when possible.²

Households use fuel in order to obtain the services of household appliances. It is assumed here that the demand by a household for a particular fuel consists of the sum of its demands for the fuel for each of its appliances using that fuel, i.e.,

$$q_i = \sum_j q_{ij} \quad (1)$$

where q_i is the household's total demand for fuel i and q_{ij} is the household's demand for fuel i for appliance j . The appliances explicitly considered in this analysis are those used for space heating, central and room air conditioning, water heating, cooking, freezing, clothes washing and drying. An "all other" category encompasses the use of electricity for lighting, refrigeration, television, dishwashers, and small electric appliances.

Assuming appliance stock fixed in the short-run, the demand for a fuel for a particular end-use is determined by the level of utilization of the given capital stock. Hence,

$$q_{ij} = U_{ij} \cdot APP_{ij} \quad (2)$$

¹See Hartman [1978].

²Attention has been given to this aspect of short-run demand by Fisher and Kaysen [1962], Acton, Mitchell and Mowill [1976], and Taylor, Blattenberger, and Verleger [1977], among others.

where U_{ij} represents the utilization of fuel i by appliance j and APP_{ij} is the stock of appliance type j which uses fuel i . In this study APP_{ij} is used to denote the number of appliances of type j using fuel i and U_{ij} is demand per appliance for fuel i .¹

Since the data used in this study consist of annual observations by state, equation (1) is summed over all households in the state to arrive at total residential demand by state for electricity and natural gas.

Demand for Electricity

Household demand for electricity is assumed to be a linear function of own price, income, and, in the case of space heating and air conditioning, of heating and cooling degree days.² Short-run demand is assumed to adjust fully to new levels of fuel prices, income, weather and appliance stocks.

¹In the studies cited above (footnote 2, p. 4), appliances are usually aggregated into a single stock measure using "normal" usage or rated capacity as weights. The appliance stock is measured in energy units and U_i is the utilization rate of the appliance stock.

Several difficulties arise with this approach which are avoided by specifications (3) and (4) below. First, it is very likely that the demands for energy for different end-uses have different elasticities. When appliances of different types are aggregated, this useful information is lost. Second, if elasticities for different end-uses vary, average elasticities will depend on the particular appliance configuration of the household or of the state. Thus, it is inappropriate to use estimates of average elasticities to project future demand if the appliance mix is changing. Likewise, an elasticity estimated by pooling state aggregated appliance data may not be a very good estimate of the elasticity for an individual state if the appliance-mix of the state is different from the typical state configuration. Third, the "normal" usage used to aggregate appliance is itself endogenous and should be modeled explicitly.

While differential elasticity estimates are useful, several problems arise in estimation: first, some of the variables are highly collinear, and second, many degrees of freedom are needed. Neither problem was felt insurmountable.

²Heating degree days are the number of degrees that the daily mean temperature is below 65°F. Annual heating degree days is the sum of the daily heating degree days. Cooling degree days are the number of degrees that the daily mean temperature is above 65°F. Annual cooling degree days is the sum of the daily cooling degree days.

Since electricity is sold under declining block price schedules, two price variables, a marginal price and a fixed charge to represent the inframarginal blocks, are generally necessary to represent the price schedule.¹ Letting i now index households, j index appliance, and suppressing the time subscript, the demand for fuel for each end use is specified as follows:

Space Heating

$$QE_{ij} = \beta_{0j} + \beta_{1j} HD_i + \beta_{2j} PE_i + \beta_{3j} FC_i + \beta_{4j} Y_i + \epsilon_{ij}$$

Central Air Conditioning, Room Air Conditioning

$$QE_{ij} = \beta_{0j} + \beta_{1j} CD_i + \beta_{2j} PE_i + \beta_{3j} FC_i + \beta_{4j} Y_i + \epsilon_{ij}$$

Freezing, Cooking, Water Heating, Clothes Washing, Clothes Drying,
All Other²

$$QE_{ij} = \beta_{0j} + \beta_{2j} PE_i + \beta_{3j} FC_i + \beta_{4j} Y_i + \epsilon_{ij}$$

where

QE_{ij} = the demand for electricity by household i for end use j

PE_i = the marginal price of electricity for household i

FC_i = the fixed charge facing household i

Y_i = personal income for household i

HD_i = heating degree days for household i

CD_i = cooling degree days for household i

ϵ_{ij} = random error

Assuming constancy of intercepts and slopes across households total

¹ See Taylor [1975], Acton, Mitchell, and Mowill [1976], and Taylor, Blattenberger, and Verleger [1977].

² The category "all other" includes the demand for electricity for lighting, refrigeration, television, dishwashers, and small appliances. No attempt is made to separate these uses of electricity either because data do not exist, electricity consumption is very small, or saturation is virtually 100 percent and the variable would be collinear with the number of households in the state which appears in the final form of the model.

demand by state is obtained by summing the individual demands over end uses (j) and households (i).

$$\begin{aligned}
 QE = & \sum_i \sum_j QE_{ij} = \sum_i (\beta_{01} + \beta_{11}HD_i + \beta_{21}PE_i + \beta_{31}FC_i + \beta_{41}Y_i)APP_{i1} \\
 & + \sum_i \sum_{j=2}^3 (\beta_{0j} + \beta_{1j}CD_i + \beta_{2j}PE_i + \beta_{3j}FC_i + \beta_{4j}Y_i)APP_{ij} \\
 & + \sum_i \sum_{j=4}^8 (\beta_{0j} + \beta_{2j}PE_i + \beta_{3j}FC_i + \beta_{4j}Y_i)APP_{ij} \\
 & + \sum_i (\beta_{09} + \beta_{29}PE_i + \beta_{39}FC_i + \beta_{49}Y_i) + \sum_i \sum_j \epsilon_{ij}APP_{ij}
 \end{aligned}$$

where $APP_{ij} = 1$ if household i owns appliance j
 $= 0$ if household i does not own appliance j

and the index j

- = 1 for space heating
- = 2, 3 for central and room air conditioning, respectively
- = 4-8 for cooking, water heating, clothes washing, clothes drying, and freezing, respectively
- = 9 for all other uses.

Using state averages for the price variables, income, and heating and cooling degree days, the summation simplifies to

$$\begin{aligned}
 QE = & (\beta_{01} + \beta_{11}\overline{HD} + \beta_{21}\overline{PE} + \beta_{31}\overline{FC} + \beta_{41}\overline{Y})E_1 \tag{3} \\
 & + \sum_{j=2}^3 (\beta_{0j} + \beta_{1j}\overline{CD} + \beta_{2j}\overline{PE} + \beta_{3j}\overline{FC} + \beta_{4j}\overline{Y})E_j \\
 & + \sum_{j=4}^8 (\beta_{0j} + \beta_{2j}\overline{PE} + \beta_{3j}\overline{FC} + \beta_{4j}\overline{Y})E_j \\
 & + (\beta_{09} + \beta_{29}\overline{PE} + \beta_{39}\overline{FC} + \beta_{49}\overline{Y})HS + \sum_i \sum_j \epsilon_{ij}APP_{ij}
 \end{aligned}$$

where

HS = the number of households in the state

E_j = the stock of appliance j in the state

Demand for Gas

Using much the same notation, short-run demand for gas by state is derived in an analogous fashion:¹

$$QG = (\beta_{01} + \beta_{11}\overline{HD} + \beta_{21}\overline{PG} + \beta_{41}\overline{Y})G_1 + \sum_{j=4,5,7} (\beta_{0j} + \beta_{2j}\overline{PG} + \beta_{4j}\overline{Y})G_j + \sum_i \sum_{j=1,4,5,7} \epsilon_{ij}^{APP} APP_{ij}$$

Unlike the model of electricity demand, there is no "all other" category for the gas equation because the use of other gas appliances is limited. The four end-uses specified here, space heating (1), cooking (4), water heating (5), and clothes drying (7) comprise almost all of the uses for residential gas demand. Notice that the average price of gas is used due to the lack of a marginal price series.

The pooled data sources for these equations are indicated in Appendix A. Given the complexity of supply and the regulatory rate-setting process, in addition to the existence of regulatory lag, it was felt that supply could be treated as exogenous for the annual demand curves estimated here.¹ It is

¹Notice that only own price is included in each demand equation. The reason is that with fixed appliance stock in the short-run, there appears to be little potential for fuel substitution. This view is supported by the results of Taylor, Blattenberger and Verleger [1977] which suggest the effects of the price of gas are insignificantly different from zero. See Werth [1979] and Hartman [1978] for further discussion.

²This assumption is supported in the literature. Mount, Chapman and Tyrrell [1973], used instrumental variables to estimate their demand model, and found that the estimates were very close to those achieved by ordinary least squares. Houthakker, Verleger and Sheehan [1974], also used an instrumental variable estimator, but their standard errors were large. Halvorsen [1973], who explicitly modeled the supply side, achieved essentially the same estimates of the demand parameters with two stage least squares and OLS.

clear from the model that heteroskedasticity exists since the error term is $\sum_i \sum_j \epsilon_{ij} APP_{ij}$. If ϵ_{ij} and ϵ_{ik} for $j \neq k$ are independent, if the errors are independent across households,¹ and if ϵ_{ij} is distributed $N(0, \sigma_\epsilon^2)$ for all i and j , then the error term is distributed $N(0, \sum_i \sum_j \sigma_\epsilon^2 APP_{ij})$. A simple procedure was adopted to correct for this. The electricity observations were weighted by dividing them by the square root of the number of households in the state and the gas observations were divided by the square root of the number of gas space heating customers in the state. The results did not appear to be very sensitive to the correction procedure used. For these weighted data, OLS was run (WLS) in addition to a fixed effects and random effects error components model.

¹If these two assumptions are not met (and it is likely they won't be) the suggested WLS correction procedure will still be consistent but inefficient.

II. Results

Tables 1-3 summarize the results for short-run electricity demand while 4 and 5 summarize gas demand results.¹ The regression equations are presented in Appendix B. Table 1, column 1 presents WLS elasticity estimates for the full equation while columns 2-4 present elasticity estimates for WLS, a fixed effects model and a random effects model exclusive of the fixed charges. The reason for excluding the fixed charge is that only three regression coefficients (for space heating, water heating and clothes washing) are negative as expected and only two are significantly different from zero.² None of the positive coefficients are significantly different from zero. Furthermore, none of the fixed charge coefficients were equal to their theoretical values.³

For all equations, the heating and cooling degree day elasticities are the correct sign and significant. The results of the remaining elasticity estimates are mixed in terms of signs and significance. For WLS(1), all elasticities (hence regression coefficients) significantly different from zero are the expected sign.⁴ However, for WLS(2), the price elasticity of electricity demand for clothes washing is positive, significant and large. Likewise the income elasticities for space heating and cooking are negative and significant. A similar positive significant price elasticity (for

¹The electricity demand (equation 3) was estimated for 1960-1972 for all states except Alaska, Hawaii, Virginia and Maryland (due to missing data). DRI [1977] appliance stock estimates were used. The gas equation (4) was estimated for 1960-1975 for all states using Braid [1978] appliance stock data. See Appendix A.

²However, the hypothesis that the fixed charge coefficients are all zero is rejected at the .01 level of significance (Werth [1978], p. 23). If the fixed charge variables belong in the regression, excluding them will generate specification error. However, as shown by Berndt [1978], the resulting bias is small.

³See Werth [1978], p. 23.

⁴For WLS(1), the hypothesis that all the price and income coefficients (hence elasticities) are zero is rejected at the .01 level of significance.

Table 1
Elasticities of the Short-Run Demand for Electricity¹

| | (1) WLS | (2) WLS | (3) Fixed Effects | (4) Random Effects |
|--|------------|------------|-------------------------|--------------------------|
| <u>Price Elasticities</u> | | | | |
| Space Heating | -.55* | -.99* | -.40* | -1.03* |
| Central Air Conditioning | -.62 | .01 | .74 | 135.19 |
| Room Air Conditioning | -1.78* | -1.55* | -1.82* | -1.57* |
| Freezing | -.17 | -.54 | -2.77 | -.33 |
| Cooking | 1.07 | .24 | -3.85* | -.15 |
| Water Heating | -.97* | -.48* | -2.31 | -.37 |
| Clothes Washing | 6.46 | 8.75* | -2.16 | 9.39* |
| Clothes Drying | .86 | -.25 | -2.31 | -.43 |
| Aggregate ² | -.19 | -.40 | -1.11 | 5.17 |
| <u>Income Elasticities</u> | | | | |
| Space Heating | -.80 | -.93* | -.06 | -.91* |
| Central Air Conditioning | .24 | .48 | .02 | .49 |
| Room Air Conditioning | -.91 | .27 | 2.86* | .82 |
| Freezing | .18 | -1.19 | 2.99 | -.89 |
| Cooking | -2.94 | -2.88* | -8.80* | -2.16 |
| Water Heating | .16 | 1.48* | .98 | 1.42* |
| Clothes Washing | 27.45* | 20.41* | -26.31* | 29.37* |
| Clothes Drying | 3.77* | 1.93* | -2.59* | 1.32* |
| Aggregate | .09 | .38 | -.55 | .54 |
| <u>Heating Degree Day Elasticities</u> | | | | |
| Space Heating | .88* | 1.06* | .85* | 1.01* |
| Aggregate | .11 | .13 | .10 | .12 |
| <u>Cooling Degree Day Elasticities</u> | | | | |
| Central Air Conditioning | .28 | .39* | .27* | .29* |
| Room Air Conditioning | .44* | .50* | 1.09* | .50* |
| Aggregate | .04 | .05 | .08 | .04 |
| <u>Fixed Charge Elasticities</u> | | | | |
| Space Heating | -.06 | | | |
| Central Air Conditioning | .05 | | | |
| Room Air Conditioning | .01 | | | |
| Freezing | .29 | | | |
| Cooking | 1.98 | | | |
| Water Heating | -1.17 * | | | |
| Clothes Washing | -10.33 * | | | |
| Clothes Drying | .69 | | | |
| Aggregate | -.22 | | | |

¹ Individual appliance elasticities are calculated at the means of the independent variables using the estimated average KWh consumption of the appliance (Table 3). For example, the WLS(1) price elasticity of demand for space heating is $\frac{\partial Q}{\partial P} \cdot \frac{P}{Q_{ij}} = -3,832 \times \frac{1.823}{12,782} = -.55$

² Aggregate elasticities are calculated by weighting each individual elasticity by the percentage of total residential demand for electricity estimated to be used for that end use. The weights were calculated by multiplying the number of appliances of each type by the estimate of average use made by Dole [1975]. See Werth [1979].

* Significantly different from zero at the 95% level.

clothes washing) occurs for the random effects model, while a negative significant income elasticity for space heating occurs in the random effects model and for clothes washing and drying and cooking in the fixed effects model.

Ignoring for a moment the unexpected signs, other estimates in Table 1 are reasonable. For instance, for WLS(1) the price elasticity for space heating is $-.55$ while the price elasticity for freezing is only $-.17$. The relative magnitude of these estimates is in the range one would expect. In general, households can vary more easily their consumption of fuel for space heating than they can for freezing. However, it is difficult to judge the individual elasticities in the absence of other estimates. Most of the WLS estimates and the random effects estimates are in the inelastic range which is in accord with prior expectation. The heating degree day elasticities of $.85 - 1.06$ are reasonable since engineering models assume an elasticity equal to 1.0 .¹ The cooling degree day elasticities are less elastic; however, the fixed effects model generates an estimate of 1.09 for room air conditioning.

In terms of the aggregate elasticities, the WLS estimates compare favorably with those from other studies, some of which are presented in Table 2. The aggregate short-run price elasticity is $-.19$ for WLS(1) and $-.40$ for WLS(2) and the aggregate short-run income elasticities are $.09$ and $.38$ respectively. Acton, Mitchell and Mowill [1976] find the short-run price elasticity to be $-.35$. Fisher and Kaysen [1962] produced estimates ranging from $-.16$ to $-.25$. Mount, Chapman, and Tyrrell [1973] estimated the short-run price elasticity to be in the neighborhood of $-.14$ to $-.36$. Other estimates in Table 2 are lower. The estimates of the short-run income elasticity range from almost zero up to $.40$. For the variance component

¹See for example, Lehman and Sebenius [1977], p. 1.

Table 2

Estimates of Elasticities from other Studies

| | <u>Short-Run Price Elasticity</u> | <u>Short-Run Income Elasticity</u> |
|--|---------------------------------------|--|
| Acton, Mitchell & Mowill [1976] | -.35 | .40 |
| Fisher and Kaysen [1962] | -.16 to -.25 | .07 to .33 |
| Mount, Chapman, and Tyrrell [1973] | -.14 to -.36 | .02 to .10 |
| Taylor, Blattenberger and Verleger [1977] | -.05 to -.54 | .0004 to .38 |
| Wills [1977] | -.08 | .32 |
| Houthakker, Verleger, and Sheehan [1974] | -.03 to -.09 | .13 to .15 |

models, the fixed effects aggregate price elasticity is -1.11 while the random effects generates an unacceptable 5.17.

The unexpected signs of several of the significant elasticities in Table 1 require discussion. These unexpected signs are cause for concern since we must remain agnostic about the consistency of the WLS and random effects model.¹ While the fixed effects model may be inefficient, it is consistent. Hence it will be useful to focus on the fixed effects estimates as a basis for discussion.

In the fixed effects model, the significant positive price elasticities are absent. Furthermore, the significant negative income elasticity for space heating demand disappears. However, significant negative income elasticities still remain for cooking, clothes drying and clothes washing. Because these results are statistically consistent, they must be reckoned with. But on reflection, these results are believable and informative. They suggest for particular end-uses, that as income rises, less electricity will be demanded for cooking, clothes drying and clothes washing. Ceteris paribus, higher income families will dine out more often and utilize laundry/dry cleaning services more often. Such results certainly corroborate the trend toward greater use of personal services for the upwardly mobile. They are more credible than the significantly negative income elasticity for WLS(2) and the random effects model.

For the four equations underlying Table 1, the estimates of average KWH consumption for each appliance are generated and compared to estimates from other sources in Table 3. In general, the estimates compare quite favorably particularly for WLS(1). With few exceptions, the relative magnitudes of energy consumption by the appliances are correct. However, the fixed effects

¹See pp. 19-21 below.

Table 3

Average Consumption Estimates for Electric Appliances

| | (KWh/yr/unit) | | | | | | |
|--------------------------|--|--|-------------|---------------|---------------|--------------------------|---------------------------|
| | <u>Edison Electric Institute</u> | <u>Stanford Research Institute</u> | <u>DoIe</u> | <u>WLS(1)</u> | <u>WLS(2)</u> | <u>Fixed Effects</u> | <u>Random Effects</u> |
| Central Heating | - | 14,153 | 13,662 | 12,782 | 9639 | 10,576 | 9,611 |
| Central Air Conditioning | - | 3,600 | 3,565 | 3,312 | 3405 | 4268 | 4137 |
| Room Air Conditioner | - | 1,375 | 1,370 | 2,333 | 1977 | 903 | 1848 |
| Freezer | 1190-1820 | 1,478 | 1,395 | 2,273 | 2742 | 490 | 2367 |
| Range | 700-730 | 1,180 | 1,200 | 649 | 1152 | -511 | 1124 |
| Water Heater | 4470-4810 | 4,490 | 4,350 | 3,033 | 2849 | 791 | 2757 |
| Clothes Washer | 100 | 100 | - | 57 | 85 | -104 | 59 |
| Clothes Dryer | 990 | 990 | 1,000 | 1806 | 3375 | 3027 | 3331 |

model generates fairly unacceptable estimates for cooking and clothes washing.

The results of the estimation of the demand for gas are tabulated in Tables 4 and 5. Actual parameter estimates are found in Appendix B, Table B2. The WLS and fixed effects price elasticities are consistently best in terms of sign. The fixed effects model generates three significant price elasticities, as does the random effects model. However, the price elasticity for cooking is the wrong sign for the random effects model. The aggregate price elasticities for all three sets of results are appropriate. A number of negative income elasticities are generated; in light of the preceding discussion, such results are reasonable for cooking and clothes drying. They seem unreasonable for space heating. However, only the WLS equation generates a positive (and insignificant) income elasticity. The significance of the consistent negative income elasticity in the fixed effects model is important while puzzling. The WLS degree day elasticity is .91, which, as in the case of electricity, is close to the value of 1 which is used in engineering models.¹

Table 5 indicates predicted annual average consumption of gas appliances and compares them to alternative estimates. For the WLS equations, the estimates for space heating and cooking are reasonable while those for water heating and clothes drying are too high. As found for electricity, the fixed effects model generates a negative estimate of annual consumption for cooking.

The discussion of Tables 1-5 has highlighted the similarities and

¹Again for example see Lehman and Sebenius [1977]. The hypothesis that the price and income coefficients (hence elasticities) are zero is rejected at the .01 level of significance for the WLS model. See Werth [1978].

Table 4

Elasticities of the Short-Run Demand For Gas

| | (1) WLS | (2) Fixed Effects | (3) Random Effects |
|--------------------------------|------------|-------------------------|--------------------------|
| <u>Price Elasticities</u> | | | |
| Space Heating | -.09 | -.05 | -.02 |
| Cooking | -1.02* | -.73* | 1.30* |
| Water Heating | -.05 | -1.64* | -1.08* |
| Clothes Drying | -1.05 | -.66* | -7.14* |
| Aggregate | -.15 | -.30 | -.21 |
| <u>Income Elasticities</u> | | | |
| | (1) | (2) | (3) |
| Space Heating | .23 | -.16* | -.17* |
| Cooking | -4.66* | -.42 | -.31 |
| Water Heating | .72 | .58 | .52 |
| Clothes Drying | -.55 | -1.02* | -16.04* |
| Aggregate | .02 | -.05 | -.21 |
| <u>Degree Day Elasticities</u> | | | |
| | (1) | (2) | (3) |
| Space Heating | .91* | .46* | .08* |
| Aggregate | .68 | .35 | .06 |

Estimated using average use in Table 5.

* Significantly different from zero at the 95% level.

Table 5

Average Consumption Estimates
for Gas Appliances
(therms/yr/unit)

| | (1) Dole | (2) ¹ | WLS | Fixed Effects | Random Effects |
|-----------------|-------------|------------------|-------|------------------|-------------------|
| | | _____ | _____ | _____ | _____ |
| Central Heating | 1040 | 880 | 815 | 1047 | 975 |
| Range | 95 | 138 | 126 | -365 | 137 |
| Water Heater | 260 | 288 | 426 | 114 | 156 |
| Clothes Dryer | 43 | 40 | 351 | 625 | 842 |

¹ C.W. Behrens, "AHAM offers Energy Saving Aids to the Public," Appliance Manufacturer, October 1974, as reported in Dole [1975].

differences between WLS results and those of a fixed effects and random effects formulation. In Table 1, it was found that the fixed effects price elasticities are generally fairly elastic, which contradicts expected short-run inelasticity. However, the major use (space heating) exhibits a reasonable and significant price elasticity (-.40). Furthermore, there are no significant price elasticities of the wrong sign. While we feel the aggregate price elasticity (-1.11) is too high, this results from using Dole's estimates of average use (Table 3) rather than those for the fixed effects model. In light of earlier discussion, the fixed effects income elasticities are believable and suggestive. The WLS and random effects models generate positive price elasticities and negative income elasticities that seem less defensible. However, both do a better job in predicting estimates of annual average use (Table 3).

In light of these differences and because the two error component models are the basis for much empirical energy demand work,¹ more evidence on the credibility of the different stochastic assumptions underlying the models is useful. The appropriate method of pooling cross-section and time-series data will depend on how well the assumptions of the model are met in reality.² If the individual effect associated with each state is a random variable with an expected value of zero and if it is uncorrelated with the right hand side variables, the random effects model produces the desired consistent and

¹For example, Balestra and Nerlove [1977] utilize a fixed effects and random effects model. While estimating both models, they stress the random effects results in spite of the fact that "dubious assumptions" are necessary. "For example, if the individuals are geographical regions with arbitrarily drawn boundaries, as they are here, we would not expect this assumption (stochastic independence across states) to be satisfied (p. 595)." Houthakker, Verleger and Sheehan [1974], Taylor, Blattenberger and Verleger [1977], Mount, Chapman and Tyrrell [1973] and Baughman and Joskow [1974, 1976] utilize the random effects model developed by Balestra and Nerlove [1966].

²See Maddala [1971], for greater clarification.

efficient estimates. (WLS) produces consistent estimates of the parameters, but not efficient ones, and the estimates of the standard errors are biased. If, however, the individual element associated with each state is correlated with the right-hand side variables, both WLS and the random effects model produce inconsistent estimates. It is highly probable that excluded supply and demographic variables are correlated with price and income. In this case, the fixed effects model still produces consistent estimates.

That some of the fixed effects estimates differ substantially from the estimates made using the other models is not surprising. As Maddala [1971] has shown, the random effects estimator for β can be written as

$$\hat{\beta} = \frac{W_{xy} + \theta B_{xy}}{W_{xx} + \theta B_{xx}}$$

where

$$W_{xx} = \sum_t (X_{it} - \bar{X}_i)^2$$

$$W_{xy} = \sum_t (X_{it} - \bar{X}_i)(Y_{it} - \bar{Y}_i)$$

$$B_{xx} = \sum_i \sum_t (X_{it} - \bar{X})^2 - W_{xx}$$

$$B_{xy} = \sum_i \sum_t (X_{it} - \bar{X})(Y_{it} - \bar{Y}) - W_{xy}$$

$$\theta = \frac{\sigma_\epsilon^2}{\sigma^2 + T\sigma_\alpha^2}$$

W refers to within groups and B refers to between groups. The ordinary least squares estimator corresponds to $\theta = 1$ and the fixed effects estimator corresponds to $\theta = 0$. The fixed effects estimator eliminates a large portion of the total variation in the data since it eliminates the between-group variation, which is much larger than the within-group variation. Since θ in the random effects model for electricity is estimated to be .667, the random effects estimates are not very different from the WLS estimates. The

elasticity estimates in Table 1 corroborate this. Furthermore, the hypothesis that the state dummy variables in the fixed effects model are all equal to 0 is rejected by an F test at the .01 level of significance. Similarly, the hypothesis that the variance of the random component in the random effects model is zero is rejected at the 0.1 level.¹

The discussion of individual elasticity estimates above helped inform us that the appropriate form of the stochastic model may be the fixed effects model. Furthermore, a specification test can be used to test the assumption of no misspecification in the random effects model.² The null hypothesis of no misspecification in electricity demand is rejected with an F test at the .01 level of significance.³ This result indicates that a fixed effects model is necessary for consistency. Since much of the work in this field utilizes a random effects approach it would be useful to look at the results of similar specification tests performed for the other studies.

For gas demand, the hypothesis that the individual state dummy variables are all equal to zero is rejected by an F test at the .01 level of significance. The hypothesis that the variance of the random term in the random effects model is zero is also rejected at the .01 level of significance by a

¹See Werth [1978], p. 43.

²A specification test developed by Hausman [1978] can be used to test whether the assumptions of the random effects model hold. The basis for the test is that if the assumptions of the random effects model hold, both the random and fixed effects models produce consistent estimates. Under the null hypothesis of no misspecification, Hausman has shown that the statistic

$$m = \frac{\hat{q}'V(\hat{q})^{-1}\hat{q}}{K}$$

is distributed as $F(K, T-K)$ where $\hat{q} = \hat{\beta}_{FE} - \hat{\beta}_{RE}$, the difference between the fixed and random effects estimates, $V(\hat{q}) = (\hat{\beta}_{FE}) - V(\hat{\beta}_{RE})$, and K is the number of coefficients. In forming $V(\hat{q})$, the estimate of σ^2 from the fixed effects model should be used in order to insure that the estimate of σ^2 is independent of \hat{q} so that m is distributed as F .

³All details of the hypothesis testing are found in Werth [1978].

chi-square test. In the case of gas, θ is estimated to be .239; hence, the random effects model is closer to the fixed effects model. This conclusion is corroborated by Tables 4 and 5. However, as in the case of the demand for electricity, a specification test rejects the hypothesis of no misspecification in the random effects model, thus indicating that WLS and random effects estimates are inconsistent.

III. Conclusions and Research Extensions

The short-run energy modeling discussed in this paper has been developed as part of a broader effort to generate a residential energy demand model that explicitly dichotomizes short-run and long-run behavior while explicitly disaggregating demand by appliance type/end-use. The latter disaggregation has aimed at estimating different elasticities by appliance type while permitting a level of analytic detail refined enough to focus on the technical characteristics of the residential energy-using stock. Such refinement will be used to incorporate disaggregated estimates of appliance efficiency, to assess the effects of specific appliance efficiency policy measures and finally to analyze the effects of new technologies.¹

The results are mixed but encouraging. Different significant price, income and weather elasticities have been estimated. Furthermore, the different elasticities have already been informative. More importantly, we have indicated that WLS and the currently popular random effects model of Balestra and Nerlove are inconsistent and inappropriate for the short-run demand modeling pursued here. Given the considerable difference between the fixed effects and WLS/random effects models, we feel that similar consistency tests should be performed in the literature.²

The consistency tests and the significant yet unexpected signs of important elasticities (particularly the income elasticity of electrical space heating demand) in the WLS and random effects models argue for dependence on the fixed effects model and its results. However, problems with the fixed

¹The particular new technology of interest is solar photovoltaics. See Hartman [1978, 1979].

²For example, for the studies listed in footnote 1, p. 19.

problems with the fixed effects results remain. Our future work will concentrate on the fixed effects model³ and that future work will include the following:

- o development and incorporation of appliance efficiency data and greater socioeconomic detail into equations 3 and 4. The efficiency data is currently being finalized for the appliances disaggregated in the paper.
- o Aggregation of minor appliances with similar price and income elasticities and efficiency characteristics.

¹ However, WLS and a random effects model will be estimated for comparison's sake and in order to continue to test the consistency of the random effects model.

Appendix A: The Data

Electric appliance stocks and the stock of gas-heated houses were obtained from the study by Data Resources, Inc.(DRI) [1977]. Gas appliance stock data for water heaters, ranges and clothes dryers were developed as a part of this study. A detailed review of the methodology used to develop the electric appliance stock data by DRI and the approach used to develop the gas appliance stock data is contained in Braid [1978]. Concern over the quality of the appliance stock data led to the development of an alternative stock series for stocks other than space heating and air conditioning. The alternative series is also discussed in Braid [1978]. It is developed by trending saturation rates obtained from census data for each appliance and for each state between the years 1960 and 1970. The series thus obtained is then adjusted to insure that state stocks sum to the national stock for each year.

Other data were obtained from the following sources. Average marginal and fixed charge electricity price data were obtained from DRI [1977]. The data were constructed by taking a customer-weighted average over different rate schedules within a state of the marginal and fixed charge prices for the average level of KWh consumption. Gas revenues and sales by state were taken from Gas Facts and the average price was calculated by dividing revenues by sales. Electricity sales came from the Edison Electric Institute Statistical Yearbook. Personal income was taken from the Survey of Current Business. Average heating and cooling degree day data was developed by taking a population weighted average of heating and cooling degree days of major population centers. Heating and cooling degree data was obtained from the National Oceanic and Atmospheric Administration. Prices and income were deflated by consumer price index and the cross-section index developed by Anderson [1973].

Appendix B: Regression Results

B1 Coefficient Estimates for the Short Run Demand
for Electricity - [DRI Data]

(Standard errors in parentheses)

| | <u>WLS(1)</u> | <u>WLS(2)</u> | <u>Fixed Effects</u> | <u>Random Effects</u> |
|---------------------------------|-------------------------|-------------------------|--------------------------|---------------------------|
| <u>Space Heating</u> | | | | |
| C | 19,449.3 (5,415.42) | 17,872.7 (4,574.2) | 6,403.51 (6,239.07) | 18,502.7 (4,770.76) |
| HD | 2.16623 (.224396) | 1.96513 (.213195) | 1.72969 (.2158) | 1.85439 (.2238) |
| PE | -3,831.58 (1,208.72) | -5,220.26 (1,107.98) | -2,309.76 (1,236.27) | -5,405.54 (1,156.14) |
| FC | -224.075 (345.854) | | | |
| Y | -1.1296 (3.97153) | -.993086 (.3941) | -.0691287 (.47266) | -.964652 (.3957) |
| KWh/appliance/year ¹ | 12,782 | 9,639 | 10,576 | 9,611 |
| <u>Central Air Conditioning</u> | | | | |
| C | 3,483.31 (6,462.41) | 446.91 (5,933.1) | -127,105 (5,178.45) | -442.2 (5,911.5) |
| CD | .792216 (.327277) | 1.15168 (.342) | .9791 (.303) | 1.015 (.346) |
| PE | -1,133.63 (1,516.02) | 17.01 (1,441.06) | 1,730.17 (1,240.48) | 748.92 (1,431.2) |
| FC | 49.2886 (464.642) | | | |
| Y | .088769 (.405312) | .1826 (.424) | .0111 (.370) | .225 (.418) |
| KWh/appliance/year ¹ | 3,312 | 3,405 | 4,268 | 4137 |
| <u>Room Air Conditioning</u> | | | | |
| C | 7,564.65 (2,870.32) | 3,510.09 (2,393.45) | -1,022.23 (2,111.13) | 3,198.93 (2,402.11) |
| CD | .873652 (.182517) | .853756 (.179396) | .840579 (.21096) | .79841 (.191889) |
| PE | -2,281.23 (577.580) | -1,678.31 (546.98) | -900.394 (493.80) | -1,591.42 (550.18) |
| FC | 7.86344 (198.558) | | | |
| Y | -.235154 (.164602) | .0589242 (.156) | .286982 (.13912) | .068732 (.15526) |
| KWh/appliance/year ² | 2,333 | 1977 | 903 | 1848 |

| | <u>WLS(1)</u> | <u>WLS(2)</u> | <u>Fixed Effects</u> | <u>Random Effects</u> |
|---------------------------------|------------------------|------------------------|------------------------|------------------------|
| <u>Freezing</u> | | | | |
| C | 1,575.96 (3,431.46) | 7,497.23 (2,721.98) | 382.44 (2,550.8) | 5,253.08 (2,802.3) |
| PE | -208.117 (723.623) | -818.27 (701.01) | -745.19 (640.29) | -431.26 (715.18) |
| FC | 191.148 (259.049) | | | |
| Y | .0454039 (.231395) | -.3621 (.2175) | .162647 (.192) | -.233 (.217) |
| KWh/appliance/year ¹ | 2,273 | 2,742 | 490 | 2,367 |
| <u>Cooking</u> | | | | |
| C | 574.209 (2,557.91) | 4,186.43 (2,032.45) | -6,975.62 (2,362.7) | 3,714.34 (2,165.6) |
| PE | 382.234 (531.623) | 153.86 (473.33) | 1079.7 (539.61) | -89.897 (492.61) |
| FC | 367.721 (237.569) | | | |
| Y | -.211413 (.168337) | -.36788 (.170) | .49898 (.167) | -.26926 (.174) |
| KWh/appliance/year ¹ | 649 | 1152 | -511 | 1124 |
| <u>Water Heating</u> | | | | |
| C | 9,041.07 (2,983.00) | -14.38 (2,436.4) | 1,842.6 (2,512.7) | -129.898 (2,510.35) |
| PE | -1,613.53 (596.213) | -743.297 (580.5) | -1000.84 (646.72) | -557.05 (604.88) |
| FC | -1,017.65 (233.839) | | | |
| Y | .0537846 (.191141) | .46813 (.1828) | .085725 (.1715) | .4331 (.182) |
| KWh/appliance/year ¹ | 3,033 | 2,849 | 791 | 2757 |
| <u>Clothes Washing</u> | | | | |
| C | -1,286.04 (919.255) | -2392.88 (732.68) | -3064.43 (522.06) | -2,226.55 (674.35) |
| PE | 201.612 (192.311) | 407.67 (179.05) | 123.17 (127.03) | 302.69 (164.8) |
| FC | -168.705 (83.3908) | | | |
| Y | .173596 (.0580157) | .1925 (.058) | .30362 (.0419) | .19234 (.053) |
| KWh/appliance/year ¹ | 57 | 85 | -104 | 59 |

| <u>Clothes Drying</u> | <u>WLS(1)</u> | <u>WLS(2)</u> | <u>Fixed Effects</u> | <u>Random Effects</u> |
|---|-------------------------|-----------------------|------------------------|-----------------------|
| C | -6,118.59 (2,825.09) | -2,279.1 (2,203.4) | 17,879.4 (2,604.02) | 372.68 (2,259.8) |
| PE | 849.349 (692.973) | -470.45 (656.32) | -3,840.1 (683.83) | -793.18 (663.27) |
| FC | 352.696 (254.135) | | | |
| Y | .755601 (.176472) | .72252 (.1733) | -871266 (.18178) | .48865 (.1732) |
| KWh/appliance/year ¹ | 1,806 | 3375 | 3027 | 3331 |
| <u>Other</u> | 1,398.97 (101.713) | 1331.60 (97.57) | 3902.2 (449.92) | 1456.71 (106.4) |
| <u>Intercept</u> | -19.149 (21.0868) | -79.4455 (20.898) | - | -52.3954 (25.96) |
| R ² | .9936 | .9928 | - | - |
| mean of the dependent variable (millions of KWh) | 2654.95 | 2654.95 | -53.6561 | 1753.3 |
| Standard error of the regression | 286.624 | 305.61 | 192.31 | 269.82 |
| Sum of squared residuals | 46,088,000 | 53,144,300 | 21,080,100 | 41,423,600 |

¹ calculated at the means of the independent variables

Source: Werth [1978].

B2: Coefficient Estimates for The Short-Run
Demand for Gas [Braid Data]

(Standard errors in parentheses)

| <u>Space Heating</u> | <u>WLS</u> | <u>Fixed Effects</u> | <u>Random Effects</u> |
|------------------------------------|-------------------------|--------------------------|---------------------------|
| C | -48.6689 (150.710) | 804.892 (111.749) | 562.257 (126.858) |
| HD | .142483 (.00389035) | .0931378 (.00580665) | .118882 (.00463314) |
| PG | -5.80559 (3.53814) | -4.50701 (3.42923) | -1.65961 (3.79839) |
| Y | .0208748 (.0141358) | -.0189052 (.00797443) | -.0185456 (.00964024) |
| Therms/appliance/year ¹ | 815 | 1047 | 975 |
| <u>Cooking</u> | | | |
| C | 882.809 (212.212) | -795.865 (161.385) | 3.98169 (162.829) |
| PG | -10.5303 (5.94445) | 21.6947 (5.04215) | 14.575 (5.40432) |
| Y | -.0651795 (.0164323) | .0171251 (.0100359) | -.0047048 (.0108568) |
| Therms/appliance/year ¹ | 126 | -365 | 137 |
| <u>Water Heating</u> | | | |
| C | 120.794 (127.963) | 230.571 (146.007) | 238.039 (146.893) |
| PG | -1.67961 (5.49556) | -15.2165 (5.60274) | -13.7007 (4.99719) |
| Y | .0338782 (.0185614) | .00729366 (.0905341) | .00892274 (.0096805) |
| Therms/appliance/year ¹ | 426 | 114 | 156 |

Clothes Drying

| | | | |
|------------------------------------|-------------------------|-------------------------|------------------------|
| C | 925.032 (549.485) | 1,717.92 (335.925) | 2,831.75 (357.229) |
| PG | -29.9698 (17.6206) | -33.714 (10.362) | -491.046 (11.1703) |
| Y | -.0214319 (.0423308) | -.0705665 (.0239859) | -1.49838 (.0259988) |
| Therms/appliance/year ¹ | 351 | 625 | 842 |
| <u>Intercept</u> | -1,545.51 (717.834) | - | -112.957 (2,075.80) |
| R ² | .9855 | - | - |
| Mean of Dependent variable | 15.2850 | -6.3934 | -1.21349 |
| Standard error of regression | 11.8337 | 4.68786 | 5.68434 |
| Sum of squared residuals | 103,066 | 14,196.4 | 23,781.4 |

¹ Calculated at the means of the independent variables

Source: Werth [1978].

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