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Fuel Choice and Aggregate Energy Demand in the Commercial Sector

Steve Cohn

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ABSTRACT

This report presents a fuel choice and aggregate demand model of energy use in the commercial sector of the United States. The model structure is dynamic with short-run fuel price responses estimated to be close to those of the residential sector. Of the three fuels analyzed, electricity consumption exhibits a greater response to its own price than either natural gas or fuel oil. In addition, electricity price increases have the largest effect on end-use energy conservation in the commercial sector.

An improved commercial energy use data base is developed which removes the residential portion of electricity and natural gas use that traditional energy consumption data sources assign to the commercial sector. In addition, household and commercial petroleum use is differentiated on a state by state basis.

FUEL CHOICE AND AGGREGATE ENERGY DEMAND IN THE COMMERCIAL SECTOR

Steve Cohn

1. INTRODUCTION

This report analyzes energy demands in the United States commercial sector. A multinominal logit model for this sector is developed using a refined commercial energy data base (for each state for the years 1968-1972) which has improved definitions of commercial sector use of electricity, natural gas and fuel oil calculated without the uncertain approximations and assumptions of previous studies. The model considers natural gas availability and its effect on commercial energy demand, a factor often overlooked in previous energy demand studies.

The fuel share model developed is not used in forecasting energy demand by itself, rather it is used as a submodel in an economic-engineering model of the commercial sector[1] — a model disaggregated by commercial building type which simulates commercial energy use by fuel type and end use from 1970 to 2000.

Initially, the results of a fuel share model developed by Baughman and Joskow[2] (B&J) were used in the ORNL commercial energy use model. B&J developed a dynamic model for the 1968-1972 period using combined household/commercial data. Our requirements justified the development of a model representing solely the commercial sector.

The commercial sector can be loosely defined as those businesses and organizations that provide services such as retail and wholesale trade, finance, insurance, real estate, lodging services, medical services and public administration.

Three recent studies analyze the demand for energy in the combined household/commercial sectors using a market share approach.[2,3,4] Behavior of commercial establishments with regard to factors influencing their energy use patterns can be estimated only approximately using the results of these combined sector studies. Does the commercial sector have an energy demand response as great as the residential sector? Or does the percentage of total response of commercial energy use to changes in prices or other explanatory variables in the first and succeeding years compare closely with the response estimated for the combined household/commercial sector? This study attempts to answer these questions.

Tables 1 and 2 compare energy use by fuel and end-use for the residential and commercial sectors. Compared to the residential sector which consumed 22% of the national energy use in 1975, the commercial sector used only 13%. However, the growth rate of energy use in the commercial sector during its period of peak growth from 1955 to 1973 was 5.1% per year compared with 4.0% per year for the household sector. This comparison, combined with energy conservation studies which calculate large energy savings for commercial buildings, indicate that an analysis of commercial fuel choice and price response approaches the importance of residential energy demand studies.

Table 1. Residential energy use by fuel and end use: 1975

	Electricity	Gas	Oil	Other[a]	Total
	(QBtu)				
Space heating	1.36	3.81	2.35	0.54	8.06
Water heating	1.05	0.96	0.18	0.05	2.24
Refrigerators	0.92				0.92
Freezers	0.38				0.38
Cooking	0.46	0.29		0.01	0.76
Air conditioning	1.08				1.08
Lighting	0.90				0.90
Other	0.86	0.45			1.31
Total	7.01[b]	5.51	2.53	0.60	15.65

[a]Other fuels include coal, coke and LPG.

[b]Electricity values are in primary energy use: 11,500 Btu/kWhr.

Sources: references 5, 6, 7, 8.

Table 2. Commercial energy use by fuel and end use: 1975

	Electricity	Gas	Oil	Other[a]	Total
	(QBtu)				
Space heating	0.33	1.66	1.88	0.12	3.99
Air conditioning	1.83	0.14			1.97
Water heating	0.04	0.08	0.10		0.22
Lighting	2.09				2.09
Other	0.76	0.17			0.93
Total	5.05[b]	2.05	1.98	0.12	9.20

[a]Other fuels include coal, coke, and LPG.

[b]Electricity values are in primary energy use: 11,500 Btu/kWhr.

Sources: references 1, 5, 6, 7.

2. MODEL SPECIFICATION

A multinominal logit formulation was chosen as the functional form to explain market shares of the three main fuel types (electricity, natural gas and fuel oil) used in the commercial sector as a function of prices of these fuels, per capita disposable income, climatic variables and a variable representing the availability of natural gas. The multinominal logit model developed in this study is similar to McFadden's work on transportation alternatives[9] and Baughman and Joskow's study on energy use in the combined residential/commercial sector.[2] The logit or fuel share model is represented as:

$$\ln\left(\frac{S_g}{S_e}\right)_{i,t} = \alpha_0 + \alpha_1 \ln\left(\frac{P_g}{\lambda_g P_e}\right)_{i,t} + \alpha_2 \ln PCI_{i,t} + \alpha_3\, G_{i,t}$$

$$+ \alpha_4\, CDD_{i,t} + \alpha_5\, HDD_{i,t} + (1 - \alpha_6)\ln\left(\frac{S_g}{S_e}\right)_{i,t-1}$$

$$+ \varepsilon 1_{i,t}$$

$$\ln\left(\frac{S_o}{S_e}\right)_{i,t} = \beta_0 + \beta_1 \ln\left(\frac{P_o}{\lambda_o P_e}\right)_{i,t} + \beta_2 \ln PCI_{i,t} + \beta_3\, G_{i,t}$$

$$+ \beta_4\, CDD_{i,t} + \beta_5\, HDD_{i,t} + (1 - \beta_6)\ln\left(\frac{S_o}{S_e}\right)_{i,t-1}$$

$$+ \varepsilon 2_{i,t}$$

$$S_g + S_e + S_o = 1 \ , \ \alpha_1 = \beta_1 \ , \ \alpha_6 = \beta_6$$

where S_k and P_k are the market share and state level average fuel price for fuel type k (electricity, natural gas and fuel oil). The characteristic of "independence of irrelevant alternatives" in the derivation of the multinomial logit formulation requires the price coefficient in each of the fuel share equations to be identical. In addition, for the price coefficients to maintain long-run consistency the coefficients of the lagged dependent variables in each fuel share equation are constrained to be equal. The market shares are further defined as:

$$S_g = \frac{\lambda_g Q_g}{Q_t}\ ,\ S_e = \frac{Q_e}{Q_t}\ ,\ S_o = \frac{\lambda_o Q_o}{Q_t} \text{ and } Q_t = Q_e + \lambda_g Q_g + \lambda_o Q_o\ .$$

Q_k is the annual consumption of fuel k in Btu.

Since natural gas and fuel oil are predominantly space heating fuels in the commercial sector, the state level consumption of these fuels (Q_g and Q_o) are multiplied by their space heating efficiency factors to convert their annual consumption to effective Btu. "Effective Btu" is defined as the space heating energy a fuel delivers after its conversion into useful heat. Both natural gas and fuel oil deliver slightly more than half of their total energy content as space heating energy to commercial buildings. λ_g and λ_o are the space heating conversion efficiency factors for gas and oil, assumed to be 0.60 and 0.55 respectively.[10] Electric space heating (which consisted mainly of resistance heating during the sample period of 1968 through 1972) converts each Btu of electricity delivered into one Btu of useful heat; therefore λ_e equals one and does not modify Q_e. The price variables are converted to dollars per million effective Btu by dividing the reported fuel prices by their space heating efficiency factors. This raises the effective price of natural gas and fuel oil used for space heating to almost twice their delivered price. The actual expenditures on fuel k are not altered since $(\lambda_k Q_k)\cdot(P_k/\lambda_k)=Q_k\cdot P_k$.

$G_{i,t}$, the percentage change of miles of distribution gas pipeline over a two year period, is a measure of natural gas availability in state i for year t. Per capita disposable income ($PCI_{i,t}$) is included in the share equations as a proxy for the level of consumer demand for commercial outputs. $CDD_{i,t}$ and $HDD_{i,t}$ are annual cooling and heating degree days for state i.

A desirable and plausible characteristic of this formulation is that when a particular market share approaches unity (complete saturation) the own-price market share elasticity approaches zero. Conversely, when the market share of fuel k approaches zero, the own-price market share elasticity increases. The cross-price market share elasticities react in an opposite fashion to own-price market share changes; as a fuel share approaches saturation its cross-price market share elasticity increases. These analytically derived market share elasticities are reported in Table 3.

Table 3. Short-run market share elasticities with respect to price

	S_e	S_g	S_o
P_e	$\alpha_1(1-S_e)$	$-\alpha_1 S_e$	$-\alpha_1 S_e$
P_g	$-\alpha_1 S_g$	$\alpha_1(1-S_g)$	$-\alpha_1 S_g$
P_o	$-\alpha_1 S_o$	$-\alpha_1 S_o$	$\alpha_1(1-S_o)$

The long-run market share elasticities are calculated by dividing α_6 into each of the short-run elasticities.

As mentioned earlier, $G_{i,t}$ is a variable representing natural gas availability for a particular state in year t and is defined as the percentage change of miles of distribution gas pipeline from year t-2 to the year t. (Δt = 2 years.) States where the supply of natural gas is increasing due to population growth or expanding markets might expect to have its distribution system of natural gas pipelines increasing over time, with $G_{i,t}$ picking up this supply effect. $G_{i,t}$ is expected to have a value of zero or close to zero for those states with a decline or no change in natural gas availability. The sign of coefficient α_3 in the first fuel share equation is expected to be positive; β_3 can be either positive or negative.

Other natural gas availability variables were tested in the fuel choice model with poorer results than those obtained with percentage change of miles of gas pipeline. Total miles of gas pipeline, miles of gas pipeline per square mile, miles of gas pipeline per capita and percentage change of miles of gas pipeline for a one year period all had lower t-statistic values than percentage change of miles of gas pipeline over a two year period. Testing the percentage change of miles of gas pipeline over a greater period than two years was not possible since state data earlier than 1966 was not available.

CDD and HDD are cooling and heating degree days respectively. The signs of α_4 and β_4, the CDD coefficients, are expected to be negative since they influence electricity use. The HDD coefficients, α_5 and β_5, are expected to be positive since natural gas and oil are predominantly used as space heating fuels in the commercial sector.

The fuel share models are dynamic in structure in order to determine the one-year or short-run effects of the explanatory variables on fuel shares. The long-run response for each variable is found by dividing its coefficient by α_6. (α_6 and β_6 measure the percentage of total response to changes in price ratios and other explanatory variables in the first year, $\alpha_6(1-\alpha_6)$ in the second year, $\alpha_6(1-\alpha_6)^2$ in the third year, etc.)

With just the above two fuel share equations we are able to determine only the change in relative market shares from a new price scenario. To determine the effect of a fuel price (or prices) change on the overall consumption of energy in the commercial sector, an aggregate energy demand equation must be added to the model. In addition, only by including an aggregate demand equation can we determine conventional price and cross-price demand elasticities by a simulation procedure. This equation is assumed to follow a flow adjustment structure:

$$\ln Q_{i,t} = \gamma_0 + \gamma_1 \ln P_{i,t} + \gamma_2 \ln FLR_{i,t} + \gamma_3 \ln PCI_{i,t} + \gamma_4 CDD_{i,t}$$

$$+ \gamma_5 HDD_{i,t} + \gamma_6 G_{i,t} + (1 - \gamma_7) \ln Q_{i,t-1} + \varepsilon_{3i,t}$$

where $Q_{i,t}$ is the total energy (in effective Btu) consumed by state i in year t in the commercial sector. $P_{i,t}$ is the price of energy (in \$/effective Btu) weighted by fuel shares, such that

$$P_{i,t} = (S_e \cdot P_e + S_g \cdot P_g/\lambda_g + S_o \cdot P_o/\lambda_o)_{i,t} \text{ .}$$

It is expected that γ_1 be negative and smaller in absolute value than the fuel share simulated own-price elasticities, since responses to total energy price increases can only be made with changes in usage and/or technological efficiency improvements, whereas changes in individual fuel prices can be met by fuel switching in addition to altered usage and efficiency increases.

$FLR_{i,t}$ represents the stock of commercial floor space in the commercial sector for state i in year t. Stock of floor space captures the effect of energy using capital in the commercial sector. Ideally the quantities and equipment sizes of space heating, cooling, lighting, water heating and the other commercial end uses better explain the level of commercial energy use, but this information is not available. Actually the stock of floor space is an excellent variable representing energy consuming capital stock in the commercial sector, since almost 90% of energy use in the commercial sector is space heating, cooling, and lighting which correlates closely with floor space. The sign of γ_2, the FLR coefficient should be positive. In addition, the long-run elasticity of FLR, γ_2/γ_7, should be near unity since one would expect close to a one to one correspondence between stock of floor space and energy consumption.

$PCI_{i,t}$, which represents per capita disposable income, is included in the aggregate demand equation since consumer demand for commercial services as well as the level of commercial floor space influences total energy use. Its coefficient, γ_3, is the short-run income elasticity of total energy use and is expected to be positive.

CDD and HDD are cooling and heating degree days. Their coefficients, γ_4 and γ_5 are expected to be positive.

It is uncertain whether the sign of the gas availability variable should be positive or negative in the total demand equation.

3. DATA

The traditional energy consumption sources[5,6,7] which give data for what is commonly refered to as the commercial sector, do not meet the definition of energy use in commercial buildings analyzed by the ORNL modeling efforts. Our definition consists of activities in the following Standard Industrial Classification[11] divisions:

SIC Division	Description of activity
F	Wholesale trade
G	Retail trade
H	Finance, insurance, and real estate
I	Services
J	Public administration
Part of E	Transportation, communication, electricity, gas, and sanitary services

Only commercial activities involved in post office buildings, transportation terminals, and communications and utilities buildings are of interest in SIC division E. Energy use in the above activities due to transportation is excluded.

The commercial sector data for electricity consumption is based primarily on Edison Electric Institute's Small Light and Power classification. Most utility companies classify customers as Commercial or Industrial using one of three criteria: (1) Standard Industrial Classification system (SIC), (2) predominant kWhr use, (3) classify as commercial those customers whose demands or annual use are less than specified limits.

Consequently, there is the possibility that large commercial activities such as very large office buildings will be included in the

Large instead of Small Light and Power classification. Conversely, there will be some small industrial firms classified as Small Light and Power by utilities using the second and third criteria. In general, most electric utilities do not classify or report electricity consumption by the SIC system so there are inconsistencies in claiming small light and power represents solely commercial activities.

In addition to the Small Light and Power classification, electricity sales in the other public authorities[12] category are included in our definition of the commercial sector.

Electricity service to mass-metered apartments (greater than 4 units per building) are included in Edison Electric Institute Small Light and Power classification. Electricity sales from this residential component should be subtracted from the commercial energy use data. A study by Jack Faucett Associates[13] estimates that these multi-family dwellings use 4% of residential electricity sales nationally.

Subtracting a constant 4% of residential sales from each state is a crude and probably inaccurate adjustment to make to commercial electricity consumption. By examining electric space heating and other electric appliance use in 1970 for mass-metered apartment buildings in Bureau of Census tapes,[14] a more accurate state level representation of this energy use component is estimated. The methodology for estimating multi-family electricity use is given in Appendix A.

Commercial sector natural gas use, as reported by AGA in *Gas Facts*,[15] is more closely tied to "the nature of the customer's primary business or economic activity at the location served" than commercial electricity use. AGA's definition of commercial gas customers is: "service to customers primarily engaged in wholesale or retail trade, agriculture, forestry, fisheries, transportation, communication, sanitary services, finance, insurance, real estate, personal services (clubs, hotels, rooming houses, five or more households served as a single customer, auto repair, etc.), government, and to service that does not directly come in one of the other classifications of service."

The agriculture, forestries, and fisheries (AFF) component of natural gas use represents approximately 2% of gas used in the commercial sector for 1971. The AFF natural gas use[16] is available for 1971 and 1972 on a state basis and is subtracted from the total commercial gas use figures. AFF gas consumption data for 1967-1970 are not available from AGA so adjustments were made on a state basis by subtracting 1971 state AFF figures, multiplied by the AFF gross product ratio of the year in question to 1971,[5] from the total commercial values. The errors resulting from this adjustment are probably not serious considering the small fraction of AFF gas used in AGA's commercial category.

Included in gas use for the commercial sector is gas sales reported in an "other" category by AGA referring to the public administration sector. The "other" category contains gas sales to municipalities for electric generation which must be subtracted from the "other" category. As with AFF, state level data for gas sales for electric generation are available for 1971 on, with only national figures available for 1970 and earlier. Consequently, state level data for this component for 1967 to 1970 is "created" by the following expression:

$$GSEG_{i,t} = GSEG_{i,71} \cdot \frac{GSEG_{US,t}}{GSEG_{US,71}}$$

where $GSEG_{i,t}$ refers to gas sales for electric generation included in "other" category for state i and year t.

Natural gas sales for multi-family units (>4 units) billed as one customer are also subtracted from the commercial gas use data. Personnel from AGA[17] estimated this fraction of commercially billed gas sales to be 22.2% for 1970. By analyzing the census of housing tapes for gas appliance use in 1970 on the state level, a lower estimate of 11.8% for the U.S. is calculated with considerable variation among states. (See Appendix A.)

Oil use in the commercial sector includes both residual and an unknown fraction of distillate fuel oils used for space heating.[7] A value of 35% of distillate fuel oils used in the commercial sector was estimated for AGA's TERA model as described in the National Energy Outlook for 1976.[18] Their approach was to determine, on a geographical basis, the number of residential oil-burning space heating units multiplied by an average energy use estimate to calculate residential distillate use. This value was subtracted from reported distillate sales to derive commercial sector distillate oil use. Our study further refines this approach by considering all oil burning residential appliances (space heating as well as water heating and cooking by oil) for each state obtained from an analysis of the 1970 census of housing tapes, and multiplying this stock of appliances by appliance energy use estimates developed for each state by housing type. The results of these calculations yielded 30.4% of reported 1970 distillate oil consumption for the U.S. to be allocated to the commercial sector (see Appendix A for a detailed description of this method). The calculated state level fractions of 1970 commercial distillate fuel oil use are applied to all years of the time span studied in this report.

If the state commercial energy consumption values for the three fuels are not adjusted to exclude their residential energy use components (mass-metered apartment use of electricity and natural gas and the residential sector's share of distillate oil) an econometric model with an "errors-in-equation"[19] condition will occur. This is not as serious a problem with electricity and natural gas as long as the mass-metered fuel use components and residuals of the estimated equations are distributed normally and independent of each other. However, this is not the case with fuel oil. The estimated commercial distillate oil use varies so widely across regions that only by correcting the fuel oil use for each state can serious estimation errors be avoided.

Commercial petroleum prices are represented by Platt's price series of no. 6 residual fuel oil[20] since a weighted average no. 2 and no. 6 fuel oil price series was not a statistically significant variable in the demand model.

As mentioned earlier, the level of commercial floor space by states is a reasonable proxy for the stock of energy using capital in the commercial sector. No state level commercial floor space estimates exist for the time period of interest in this study. Consequently an effort was undertaken at ORNL[21] to estimate state floor space for each commercial subsector for 1970 (Appendix B contains the methodology for calculating the commercial stock of floor space on a state by state basis from 1968 through 1972).

Heating degree-days[22] and cooling degree-days[23] are used as explanatory variables to account for the effects of weather on fuel consumption for space heating and cooling.

4. ESTIMATION AND EMPIRICAL RESULTS

As described in section 2, three equations were estimated for this model: two fuel share equations and the aggregate demand equation estimated simultaneously by joint generalized least squares using state dummies. The fuel share price ratio coefficients are constrained to be equal along with the coefficients of the lagged dependent variable.

Due to the problem of autocorrelation of the error term with the lagged dependent variable using the flow adjustment model structure, an instrumental variable approach is used.[24] The lagged dependent variable in each of the three equations is regressed on all the independent variables in the model including state dummies to eliminate any cross-sectionally related errors. The fitted values of the two lagged dependent variables are then substituted into their respective equations allowing the coefficients of the regressors to be consistent.

The estimation results for the two fuel share equations are:

$$\ln\left(\frac{S_g}{S_e}\right)_{i,t} = \underset{(-1.26)}{-0.530} - \underset{(-4.16)}{0.370}\ \ln\left(\frac{P_g}{P_e}\right)_{i,t} - \underset{(-1.21)}{0.220}\ \ln PCI_{i,t}$$

$$- \underset{(-1.76)}{0.013}\ CDD_{i,t} + \underset{(3.99)}{1.198} \times 10^{-4}\ HDD_{i,t} + \underset{(2.23)}{4.08}\ G_{i,t}$$

$$+ \underset{(7.49)}{0.603}\ \ln\left(\frac{S_g}{S_e}\right)_{i,t-1} \qquad R^2 = 0.986$$

$$\ln\left(\frac{S_o}{S_e}\right)_{i,t} = \underset{(-7.55)}{-8.768} - \underset{(-4.16)}{0.370} \ln\left(\frac{P_o}{P_e}\right)_{i,t} + \underset{(3.88)}{2.437} \ln PCI_{i,t}$$

$$+ \underset{(5.50)}{0.137}\, CDD - \underset{(-0.06)}{5.83 \times 10^{-6}}\, HDD + \underset{(0.74)}{4.627}\, G_{i,t}$$

$$+ \underset{(7.49)}{0.603} \ln\left(\frac{S_g}{S_e}\right)_{i,t-1} \qquad R^2 = 0.949$$

(t-values are in parentheses)

The results show highly significant price coefficients (representing short-run response) with absolute magnitudes in the range of other studies of the commercial or combined household/commercial sector but somewhat higher than estimated by Baughman and Joskow. B&J estimated their model without cross-sectional dummies which could account for this difference (estimating our commercial fuel share equations without state dummies gave considerably smaller price coefficients with lagged dependent variable coefficients closer to 1.0). Short-run response is mainly a usage response, whereas changes in ownership of energy using capital and improvements in equipment efficiency are included in long-run coefficients. Therefore, it can be argued that decisions on space heating, cooling and lighting usage by commercial firms show a similar response to energy price changes in the short-run as their counterparts in the residential sector. The positive and significant coefficient of HDD in the gas to electricity equation clearly shows the effect of climate on gas used for space heating by commercial buildings. It is uncertain why the HDD in the oil to electricity equation is not significant considering the fact that 95% of oil use in the commercial sector in 1975 was for space heating (for gas this value is 81%). The CDD coefficient exhibits the correct sign in the gas to electricity equation but not in the oil to electricity equation (CDD may be picking up the effects of an omitted variable in the oil equation). The coefficient of G, the percentage change in miles of distribution gas pipeline over a two year period, exhibits the correct sign in the gas to electricity equation and is more significant than the coefficient of G in the oil to electricity equation. This variable is essential in the gas to electricity equation, since it allocates part of the demand response (normally attributed to the gas price coefficient in many natural gas demand studies) to the effects of gas availability.

The results of the aggregate demand equation for the commercial sector are as follows:

$$\ln Q_{i,t} = \underset{(-1.59)}{-1.385} - \underset{(-1.99)}{0.183} \ln P_{i,t} + \underset{(2.58)}{0.354} \ln PCI_{i,t} + \underset{(2.55)}{0.412} \ln FLR_{i,t}$$

$$+ \underset{(0.16)}{6.56 \times 10^{-4}} CDD_{i,t} + \underset{(1.55)}{2.61 \times 10^{-5}} HDD_{i,t} + \underset{(7.22)}{0.601} \ln Q_{i,t-1}$$

$$R^2 = 0.997$$

All coefficients are of the correct sign with the stock of floor space having a greater statistical significance than the aggregate price term in the total commercial demand equation. The long-term price elasticity of total demand is -0.46. This is the long-run response to an increase in the weighted average energy price. The long-run floor space elasticity of total energy demand is 1.03. One would expect this elasticity to be close to 1.0 since a 1% increase in energy using capital should cause close to a 1% increase in commercial energy use. The long-run income elasticity of demand is 0.59 and represents the effect of commercial activity on total energy demand.

Using a method similar to Baughman and Joskow, conventional fuel price elasticities are calculated by the following simulation technique using both fuel share equations and the total demand equation:

1) increase one of the fuel prices by 1%.
2) calculate new market shares from the two fuel share equations and the relationship $S_e + S_g + S_o = 1$.
3) calculate a new aggregate price index from the new market shares.
4) calculate new total energy demand from the aggregate demand equation.
5) multiply the new market share from step 2 times the total demand calculated in step 4 to arrive at new consumption levels for each fuel.
6) own and cross-price elasticities for the disturbed fuel price can now be calculated.
7) repeat steps 1 through 6 for the other two fuels.

Using the above procedure with 1975 commercial energy prices and consumption values, the price elasticity matrix of Table 4 is calculated. The long-run own-price elasticities for electricity and natural gas are somewhat lower than results from other studies dealing mainly with the residential or combined residential/commercial sectors.

Fuel oil has a long-run own price elasticity which falls within the wide range of results from other studies.

Table 4. Price elasticity matrix (1975)

Fuel type	P_e	P_g	P_o	Market shares
Electricity				
Short-run	-0.343	0.094	0.067	0.273
Long-run	-0.803	0.183	0.166	
Gas				
Short-run	0.024	-0.274	0.067	0.375
Long-run	0.121	-0.741	0.166	
Oil				
Short-run	0.024	0.094	-0.300	0.352
Long-run	0.121	0.183	-0.758	

The fuel oil elasticities are not directly comparable with results of other studies since this study includes not only residual fuel but a fraction of distillate fuel oil used for space heating.

Examining the cross-price elasticities it is noted that fuel switching to the two fossil fuels in response to electricity price increases is less than the demand change for electricity when natural gas or fuel oil prices change. This is probably explained by the lack of substitutes for the main commercial sector electric end uses. In addition, electric space heating comprises only 8% of total commercial heating demand for all three fuels.

The conventional fuel demand elasticities calculated by the simulation procedure described above also change when different market share and fuel price assumptions are used. However, the new fuel demand elasticities do not have the predicted results of the market share elasticities described earlier. Not only do new market shares alter the results, but the new price levels also contribute to different fuel demand elasticities.

Simulated long-run price elasticities for total end-use energy in the commercial sector are also calculated.

	P_e	P_g	P_o
Total primary energy elasticity	-0.261	-0.099	-0.095

These elasticities indicate that electricity price increases have roughly three times the effect on total long-run commercial primary energy demand that equal percentage price increases of natural gas and oil have.

5. SUMMARY

This study developed a model describing price response in the commercial sector using a highly refined data base. Multi-family energy use reported in commercial sector energy sources is removed on a state by state basis. Commercial (as well as residential) oil use is defined more accurately than in previous studies.

A more accurate representation of natural gas demand is estimated using an explanatory variable to capture the effects of natural gas availability.

The capital stock of energy using equipment is represented by the level of commercial sector floor space in the aggregate demand equation.

Natural gas and fuel oil demand have smaller responses to their own-price than does electricity, with electricity price having the greatest impact on total energy conservation in the commercial sector. Commercial sector short-run usage response to fuel prices is similar to results reported in other residential demand studies leading one to conclude that fuel price increases will have at least the benefits for energy conservation in the commercial sector as they would for the household sector.

Tables 5 and 6 compare the estimated short-run and long-run fuel price elasticities developed in this study to those developed in several recent studies of energy demand in the commercial or combined residential/commercial sectors.

The short-run elasticities developed in this study are in the range of those reported in other studies for the commercial as well as household/commercial sectors. The Baughman and Joskow short-run elasticities tend to be from one-half to two-thirds times the magnitude of our results. Their results imply that the short-term change in utilization rate of the fixed stock of energy-using capital in the commercial sector due to fuel price changes is possibly greater than the corresponding utilization rate changes of appliances in the residential sector.

With the exception of natural gas, our long-run elasticities shown in Table 6 fall within the range of those estimates from other studies. The long-run own-price elasticities are interpreted as changes in fuel use due to fuel price induced equipment efficiency improvements, fuel switching by changes in equipment ownership and behavioral changes in fuel use. Our own-price elasticity for electricity is smaller in absolute magnitude than all but FEA's estimate reported in Table 6 and is the largest long-run elasticity estimated in this study for the three fuel types.

The fuel choice and aggregate energy demand model adjusted by the lagged dependent variable coefficients to reflect long term equilibrium

Table 5. Short-run fuel price elasticities of demand

Fuel	Source	P_{elec}	P_{gas}	P_{oil}
Electricity	This study[a]	-0.343	0.094	0.067
	Baughman & Joskow (ref. 2)[b]	-0.187	0.045	0.011
	Uri (ref. 26)[a]	-0.34		
	DOE (ref. 27)[a]	-0.25	0.019	0.012
Natural gas	This study[a]	0.024	-0.274	0.067
	Baughman & Joskow[b]	0.006	-0.15	0.011
	Berndt & Watkins (ref. 28)[b]		-0.20	
	DOE[a]	0.066	-0.30	0.010
Oil	This study[a]	0.024	0.094	-0.300
	Baughman & Joskow[b]	0.007	0.040	-0.179
	DOE distillate[a]	0.052	0.016	-0.29
	DOE residual[a]	0.106	0.024	-0.37

[a]Commercial sector demand study.

[b]Household/commercial sector demand study.

Table 6. Long-run fuel price elasticities of demand

Fuel	Source	P_{elec}	P_{gas}	P_{oil}
Electricity	This study[a]	-0.803	0.183	0.166
	Baughman & Joskow[b]	-1.003	0.170	0.046
	Chern (ref. 3)[b]	-1.46	-0.015	0.29
	Halvorsen (ref. 29)[a]	-1.157		
	Uri[a]	-0.85		
	DOE[a]	-0.64		
Natural gas	This study[a]	0.121	-0.741	0.166
	Baughman & Joskow[b]	0.169	-1.009	0.055
	Chern[b]	0.92	-1.50	0.51
	Berndt & Watkins[b]		-0.90	
	DOE[a]		-0.95	
Oil	This study[a]	0.121	0.183	-0.758
	Baughman & Joskow[b]	0.156	0.185	-1.121
	Chern[b]	0.215	0.81	-1.61
	DOE distillate[a]			-0.64
	DOE residual[a]			-0.69

[a]Commercial sector demand study.

[b]Household/commercial sector demand study.

choices is used in the ORNL commercial sector energy demand model[25] primarily to determine the long-run fuel preferences in space heating and how they relate to the estimation of floor space fractions of space heating. Space heating is the only significant end use in the commercial sector allowing choices between the three major fuels. Short-run (one year) changes in fuel shares due to fuel price changes are assumed to be utilization changes only, without fuel switching, therefore only fuel-specific short-run own-price elasticities are used to determine short-run fuel share changes. Since short and long-run effects are handled separately in the ORNL commercial model, the estimated fuel choice short-run coefficients are subtracted from the calculated long-run coefficients to avoid double counting.

One problem with the model is that the Koyck lag structure used implicitly assumes a dynamic adjustment for not only price changes, but also weather, floor space, per capita income and gas availability. Inclusion of lagged values for the non-price independent variables in the model would have avoided this problem, but at the cost of losing one year of data in the estimation. Another problem with the model is that the multinomial logit functional form restricts each pair of cross-price elasticities for a particular fuel price to be identical. Nevertheless, it is felt that developing more accurate commercial energy use data, including commercial floor space and natural gas availability as independent variables, and paying close attention to estimation technique combine to yield a model and elasticities that more accurately reflect behavior in the commercial sector than do previous models.

Appendix A

I. Procedure to separate mass-metered multi-family (>4 unit) electricity use from EEI Small Light and Power electricity consumption values

The following relationship is used for 1970 for each state:

$$\frac{X}{\text{Estimate of mass-metered multi-family elec. use (Derived from Census of housing 5\% sample)}} = \frac{\text{Residential sector elec. use (reported by EEI)}}{\text{Estimate of non-mass-metered residential elec. use (Derived from Census of housing 5\% sample)}}$$

where X = estimated U.S. mass-metered multi-family electricity use. The Census of housing 5% sample tapes[14] are comprised of individual household records, each containing information such as: state of residence, housing type, number of housing units in each structure, whether the electricity or gas bill is included in the rent, type of air conditioning if any, and type of fuels used for cooking, water heating, space heating, and clothes drying. The household sample size examined for each state is approximately 1/1000 of each state's population.

Electricity use in the residential sector can be broken down into eight end uses:

1) space heating (SH)
2) water heating (WH)
3) refrigeration (RF)
4) cooking (CK)
5) air conditioning (AC)
6) lighting (LI)

7) freezers (FZ) and

8) clothes drying (CD)

Each of the first six components, with the exception of cooking, comprise at least 12% of total residential electricity use in 1970.

Five housing types are included in the residential sector:

1) single-family detached

2) single-family attached

3) multi-family low-rise

4) multi-family high-rise

5) mobile homes

where electric appliance usage is assumed to vary by housing type only in the case of space heating, air conditioning and lighting. Mass-metered multi-family housing can be found in both multi-family low- and high-rise buildings. It is assumed that residents in mass-metered multi-family housing consume 35% more energy in space heating, air conditioning and lighting than those multi-family households whose electric bill is not included in their rent.[30]

So, residential electricity use can be represented as:

$$\sum_{j=1}^{5} \sum_{k=1}^{8} N_{ijk}^{E} \cdot U_{ijk}$$

where N_{ijk}^{E} is the number of electric appliances and U_{ijk}^{E} is the yearly appliance usage in kWhr for the ith state, jth housing type, and kth end use.

To develop electricity consumption values for <u>space heating</u> by housing type and state, the analysis developed by A. D. Little[31] is used (see Table 7). The electricity consumption figures for each state (by housing type) are calculated by multiplying each of the 4 census regions' consumption values times the ratio of state heating degree days (HDD) to regional heating degree days for 1970 (the regional HDD value is weighted by households).

Table 7. Average fuel consumption for space heating by type of structure, region, and fuel

Housing type	Fuel	Units	Space heating			
			Northeast	North Central	South	West
Mobile home						
	Distillate oil	(bbls)	18.15	20.93	10.00	12.2
	Natural gas	(mcf)	87.97	101.55	48.5	59.17
	Electricity	(kwhrs)	13390	15239	7237	8731
Single family detached						
	Distillate oil	(bbls)	36.91	40.13	17.39	22.81
	Natural gas	(mcf)	174.59	193.99	82.15	107.66
	Electricity	(kwhrs)	19396	21975	10606	14064
Single family attached						
	Distillate oil	(bbls)	25.09	31.25	11.67	14.03
	Natural gas	(mcf)	121.73	151.50	56.64	67.99
	Electricity	(kwhrs)	12145	15236	7032	9667
Multi-family low rise						
	Distillate oil	(bbls)	14.77	17.27	6.1	7.68
	Natural gas	(mcf)	71.58	83.71	29.58	37.24
	Electricity	(kwhrs)	6973	7940	3604	4834
Multi-family high rise						
	Distillate oil	(bbls)	13.65	15.63	5.4	6.5
	Natural gas	(mcf)	66.25	75.75	26.28	31.81
	Electricity	(kwhrs)	6446	6827	3047	4278

These figures are consumption per housing unit in 1970. They are taken from the 1974 Project Independence Task Force Report *Residential and Commercial Energy Use Patterns, 1970-1990* (report prepared by A. D. Little, Inc.), pages 80-83. The Btu values in the A. D. Little report have been converted to physical units.

To calculate annual energy usage for electric water heaters, heat requirement factors for the nine census divisions developed from an analysis by Dole[32] are used. These census division factors (relating to the energy required to heat the input water supply) are multiplied by the annual electricity consumption values for water heaters from an ORNL study[33] (for 72 gal of water/day, electricity energy use is 22.7×10^6 Btu/yr with no variation by housing type).

Electricity use for refrigeration[32] is assumed to have no variation due to region or housing type and has an electricity consumption of 3.87×10^6 Btu/yr. Similar to refrigeration, electric cooking is assumed to have a yearly energy use of 4.1×10^6 Btu (1200 kWhr/yr).

For central air conditioning electricity usage values by state and housing type, the thermal integrity factors (in Btu/ft^2·CDD) from Dole's report[32] are multiplied by estimates from Hittman Associates of floor-space for each of the 5 housing types[34] along with state cooling degree day data for 1970. For room air conditioners Dole assumes a linear relationship for all regions between room a/c usage and cooling hours above 80°F. Thus, for each state we multiply Dole's point of use energy consumption per unit for the respective region times the mean July state to regional temperature ratio and the estimated number of room units for that state in 1970.

Electricity consumption for food freezers is assumed by Dole to be constant by state and housing type (4.76×10^6 Btu/yr).

Dole reports estimates of energy consumed for residential lighting from 8 to 16% of total electricity consumed by the residential sector. Dole accepts the 16% value which is equivalent to about 1130 kWhr/housing unit/year. For our analysis we assume no regional variation in lighting; only a variation due to housing type. To calculate electricity usage due to lighting, we multiply 1130 kWhr/yr times the ratio of floorspace for housing type j to 1185 ft^2 (Dole assumes the U.S. average floorspace for all housing types to be 1185 ft^2). Table 8 gives a synthesis of floorspace by housing type for the U.S. compiled by Hittman Associates.[34]

Table 8. Average floorspace per housing type for the U.S. (ft^2)

Mobile home	720
Single-family detached	1500
Single-family attached	1300
Multi-family low-rise	810
Multi-family high-rise	895

The calculated percentage of multi-family mass-metered apartment housing electricity usage to total U.S. residential electricity consumption is 4.0%. The variation between states is considerable; South Dakota having the lowest value of 0.5% and Texas having the highest of 16.6%. Since the census of housing information is available for 1970 only, the state percentages of mass-metered apartment use, calculated by the above procedures, are applied to the electricity data for the entire time span of this study (1967 to 1972).

Table 9 gives the results of this analysis for mass-metered housing electricity use in 1970. Columns 3 and 4 give Edison Electric Institutes' reported values for residential and small light and power electricity use. Column 5 gives the calculated mass-metered electricity use with

Table 9. Residential and commercial electricity use: 1970

State	Edison Electric Institute Data: Residential	Edison Electric Institute Data: Commercial	Calculated mass-metered multi-family	%: M-F/C	%: M-F/R	Revised: Residential	Revised: Commercial
			(10^6 kWhr)				
1 MA	8910.	7211.	527.4	7.31	5.92	9437.4	6683.6
2 RI	1366.	1125.	69.7	6.19	5.10	1435.7	1055.3
3 CN	6283.	4265.	138.3	3.24	2.20	6421.3	4126.7
4 VT	1157.	479.	8.8	1.85	0.76	1165.8	470.2
5 NH	1462.	593.	31.3	5.28	2.14	1498.3	561.7
6 ME	1722.	970.	20.1	2.07	1.17	1742.1	949.9
7 NY	25212.	24874.	1845.6	7.42	7.32	27057.6	23028.4
8 PA	22376.	13427.	846.0	6.30	3.78	23222.0	12581.0
9 NJ	12121.	10185.	618.3	6.07	5.10	12739.3	9566.7
10 OH	21170.	14399.	586.0	4.07	2.77	21756.0	13813.0
11 MC	16878.	10505.	437.4	4.16	2.59	17315.4	10067.6
12 IL	20152.	17791.	658.2	3.70	3.27	20810.2	17132.8
13 IN	11899.	6268.	234.2	3.74	1.97	12133.2	6033.8
14 WI	9588.	4948.	171.4	3.46	1.79	9759.4	4776.6
15 MO	9729.	6037.	259.3	4.30	2.67	9988.3	5777.7
16 IO	6262.	3344.	88.8	2.66	1.42	6350.8	3255.2
17 MN	8001.	3228.	144.5	4.48	1.81	8145.5	3083.5
18 KA	4954.	4215.	131.7	3.12	2.66	5085.7	4088.8
19 NB	3598.	2966.	81.0	2.73	2.25	3679.0	2885.0
20 SD	1476.	754.	7.3	0.97	0.49	1423.3	746.7
21 ND	1319.	862.	15.8	1.83	1.20	1334.8	846.2
22 DL	1168.	822.	16.6	2.01	1.42	1184.6	805.4
23 MD	8269.	8388.	1209.5	14.42	14.63	9478.5	7178.5
24 WV	3327.	2095.	62.9	3.00	1.89	3389.9	2032.1
25 NC	14220.	7984.	109.1	1.37	0.77	14329.1	7874.9
26 SC	7084.	3904.	56.0	1.43	0.79	7140.0	3848.0
27 VA	11280.	7230.	671.7	9.29	5.95	11951.7	6558.3
28 GA	12607.	8037.	338.2	4.21	2.68	12945.2	7698.8
29 FL	23538.	11896.	441.0	3.71	1.87	23979.0	11455.0
30 AL	11141.	4434.	138.2	3.12	1.24	11279.2	4295.8
31 KY	7148.	3285.	181.5	5.52	2.54	7329.5	3103.5
32 TN	19247.	3266.	320.2	9.80	1.66	19567.2	2945.8
33 MS	6252.	3164.	113.4	3.58	1.81	6365.4	3050.6
34 TX	28883.	23137.	3829.1	16.55	13.26	32712.1	19307.9
35 AR	4183.	2818.	101.2	3.59	2.42	4284.2	2716.8
36 LA	9097.	5443.	205.0	3.77	2.25	9302.0	5238.0
37 OK	5834.	4484.	325.0	7.25	5.57	6159.0	4159.0
38 AZ	4050.	3989.	214.6	5.38	5.30	4264.6	3774.4
39 NM	1360.	2018.	57.1	2.83	4.20	1417.1	1960.9
40 CO	3488.	4243.	120.0	2.83	3.44	3608.0	4123.0
41 MT	1521.	1188.	48.3	4.07	3.18	1569.3	1139.7
42 WY	607.	1112.	14.4	1.30	2.38	621.4	1097.6
43 UT	1630.	1502.	24.5	1.63	1.50	1654.5	1477.5
44 NV	1915.	2004.	117.5	5.87	6.14	2032.5	1886.5
45 ID	2406.	2311.	46.0	1.99	1.91	2452.0	2265.0
46 CA	34556.	41277.	1654.6	4.01	4.79	36210.6	39622.4
47 OR	9389.	5406.	132.8	2.46	1.41	9521.8	5273.2
48 WA	16226.	7753.	346.9	4.47	2.14	16572.9	7406.1
50 US	446061.	311636.	17816.3	5.72	3.99	463877.3	293819.7

the percentage of mass-metered electricity use to commercial and residential use of electricity given in columns 6 and 7. The revised residential and commercial figures are reported in columns 8 and 9. The revised residential values are the sum of EEI residential values and estimated multi-family mass-metered electricity use. The revised commercial values are estimated mass-metered electricity use values subtracted from the EEI small light and power (commercial) values.

II. Procedure to separate mass-metered multi-family (>4 unit) natural gas use out from reported AGA commercial sector gas consumption values

A technique similar to the method of separating electricity usage of mass-metered apartment units out from EEI reported small light and power electricity usage is used for natural gas mass-metered apartments.

The following proportion is used for 1970 for each state:

$$\frac{X}{\text{Estimate of multi-family gas use (derived from census of housing 5\% sample)}} = \frac{\text{Residential gas use (reported from AGA)}}{\text{Estimate of residential gas use (derived from census of housing 5\% sample)}}$$

where we solve for X to obtain an estimate of multi-family mass-metered natural gas use.

Natural gas use in the residential sector can be broken down into four components:

1) space heating (SH),
2) water heating (WH),
3) cooking (CK), and
4) clothes drying (CD).

Residential gas use for state i is represented as:

$$\sum_{j=1}^{5} \left(N^G_{SH_{i,j}} \cdot U^G_{SH_{i,j}} + N^G_{WH_{i,j}} \cdot U^G_{WH_{i,j}} + N^G_{CK_{i,j}} \cdot U^G_{CK_{i,j}} + N^G_{CD_{i,j}} \cdot U^G_{CD_{i,j}} \right) .$$

i and j refer to state and housing type respectively. $N^G_{SH_{i,j}}$ is the number of housing units of type j using gas for space heating in state i (obtained from 1970 census of housing tapes). $U^G_{SH_{i,j}}$ is the estimated annual energy usage for housing type j in state i using gas for space heating.

The same five housing types used in the analysis of multi-family electricity use (part I, Appendix A) are used for the natural gas calculations.

The A. D. Little space heating usage values (Table 7) are used for developing gas consumption values for each state (by housing type) by multiplying each of the four reported census regions consumption values times the ratio of state HDD to regional HDD (weighed by households) for 1970. It is assumed that mass-metered apartment users consume 35% more gas for space heating than gas customers whose gas bill is not included in their apartment rent.[30]

To calculate annual energy usage for natural gas water heaters, the same regional heat requirement factors described in calculating electric water heating energy usage (Appendix A, part I) are multiplied times 35.74×10^6 Btu/year.[31]

Consumption of natural gas for cooking and clothes drying are assumed to be 9.5×10^6 and 4.3×10^6 Btu/year.[32]

The remainder of U.S. residential natural gas use comprises 8% of the total residential gas consumption[8] (gas air-conditioners, gas refrigerators, swimming pool heaters, gas-log fireplaces and decorative gas lights). This component is ignored in this analysis and is not considered a serious omission if we assume both mass-metered and the rest of residential gas users use close to the same proportions of the gas appliances in this remainder category.

The above approach results in 11.8% of commercial gas use in 1970 actually belonging to multi-family apartment usage of natural gas.

Table 10 gives the results of mass-metered apartment natural gas use in 1970. Columns 3 and 4 give the American Gas Association reported values for residential and commercial natural gas use. Column 5 gives the mass-metered apartment natural gas use as described in the above procedure. The percentage of mass-metered natural gas use to commercial and residential gas use is given in columns 6 and 7. The revised residential and commercial state natural gas use values are reported in columns 8 and 9. The revised residential values are the sum of AGA residential values and the estimated multi-family mass-metered natural gas use. The revised commercial gas use values reported in column 9 is AGA commercial natural gas use minus the estimated mass-metered gas use.

Table 10. Residential and commercial natural gas use: 1970

State	American Gas Association Data		Calculated mass-metered multi-family	%		Revised	
	Residential	Commercial		M-F/C	M-F/R	Residential	Commercial
			(10^{11} Btu)				
1 MA	857.0	288.2	55.7	19.34	6.50	912.7	232.5
2 RI	124.9	40.2	5.3	13.21	4.25	130.2	34.9
3 CN	317.2	107.8	19.5	18.10	6.15	336.7	88.3
4 VT	9.0	2.9	0.0	0.00	0.00	9.0	2.9
5 NH	37.6	12.9	7.4	57.64	19.77	45.0	5.5
6 ME	8.4	4.3	0.1	2.90	1.49	8.5	4.2
7 NY	3513.6	977.2	305.9	31.30	8.70	3819.5	671.3
8 PA	3163.9	954.9	173.9	18.21	5.50	3337.8	781.0
9 NJ	1462.9	565.6	84.2	14.89	5.76	1547.1	481.4
10 OH	4726.1	1698.5	165.5	9.74	3.50	4891.6	1533.0
11 MC	3500.0	1380.5	154.9	11.22	4.43	3654.9	1225.6
12 IL	4488.2	1890.6	233.7	12.36	5.21	4721.9	1656.9
13 IN	1566.1	706.0	61.0	8.64	3.90	1627.1	645.0
14 WI	1098.8	422.0	48.0	11.39	4.39	1141.8	374.0
15 MO	1629.5	710.9	66.2	9.32	4.07	1695.7	644.7
16 IO	961.9	550.4	33.2	6.03	3.45	995.1	517.2
17 MN	1023.8	462.0	74.5	16.12	7.28	1098.3	387.5
18 KA	963.0	368.9	23.6	6.40	2.45	986.6	345.3
19 NB	531.8	279.4	17.1	6.13	3.22	548.9	262.3
20 SD	111.1	87.2	1.1	1.24	0.97	112.2	86.1
21 ND	83.3	79.0	7.1	8.92	8.46	90.4	71.9
22 DL	82.7	31.6	3.6	11.45	4.37	86.3	28.0
23 MD	731.7	171.6	108.6	63.27	14.84	840.3	63.0
24 DC	147.4	95.6	50.1	52.40	33.99	197.5	45.5
25 WV	562.2	193.0	12.9	6.70	2.30	575.1	180.1
26 NC	273.1	171.3	7.5	4.39	2.75	280.6	163.8
27 SC	190.4	117.8	1.5	1.29	0.80	191.9	116.3
28 VA	502.2	233.5	69.3	29.67	13.80	571.5	164.2
29 GA	918.3	390.5	30.7	7.85	3.34	949.0	359.8
30 FL	166.0	198.9	4.0	2.00	2.40	170.0	194.9
31 AL	584.7	281.4	4.8	1.72	0.83	589.5	276.6
32 KY	833.2	315.8	17.6	5.57	2.11	850.8	298.2
33 TN	472.4	367.5	17.7	4.82	3.75	490.1	349.8
34 MS	328.0	160.8	4.2	2.61	1.28	332.2	156.6
35 TX	2506.2	1129.0	106.3	9.42	4.24	2612.5	1022.7
36 AR	493.3	269.9	14.4	5.34	2.92	507.7	255.5
37 LA	714.4	227.1	9.5	4.19	1.33	723.9	217.6
38 OK	796.5	382.8	18.6	4.86	2.34	815.1	364.2
39 AZ	318.6	195.7	5.3	2.73	1.68	323.9	190.4
40 NM	267.7	115.5	8.3	7.16	3.09	276.0	107.2
41 CO	804.7	543.4	47.5	8.74	5.90	852.2	495.9
42 MT	234.5	154.4	12.8	8.29	5.46	247.3	141.6
43 WY	127.4	79.2	6.5	8.15	5.07	133.9	72.7
44 UT	470.8	65.1	17.2	26.36	3.64	488.0	47.9
45 NV	77.2	47.7	2.9	6.12	3.78	80.1	44.8
46 ID	77.9	59.2	2.6	4.38	3.33	80.5	56.6
47 CA	5819.2	2103.7	230.3	10.95	3.96	6049.5	1873.4
48 OR	196.1	113.2	2.4	2.08	1.20	198.5	110.8
49 WA	327.8	200.1	12.1	6.06	3.70	339.9	188.0
50 US	49226.4	20035.9	2367.2	11.81	4.81	51593.6	17668.7

III. Procedure to estimate residential petroleum use from the Bureau of Mines reported sales of fuel oil and kerosene in 1970

In the ORNL commercial energy use model it is assumed that commercial users of oil consume all of reported sales of residual oils nos. 5 and 6 for heating purposes and a fraction of distillate oils sold for heating purposes (nos. 1, 2, and 4). Initially, 35% of distillate fuel oil for heating purposes[1] was used as an estimate of distillate use for the U.S. commercial sector, however, this study required a more detailed state level analysis of fuel oil usage.

This study assumes that all distillate oil sales in the U.S. for heating purposes are allocated entirely to the household and commercial sectors. Much better information exists for fuel use in the residential sector, so this study estimates total household fuel oil use (kerosene as well as distillate) and subtracts household distillate oil consumption from total distillate sales to arrive at the commercial sector's use of distillate oil. The census of housing tapes for 1970 were analyzed to determine the stock of oil burning appliances (space heating, water heating, cooking) in the residential sector on the state level. These stock estimates are multiplied by average oil appliance use figures[31,32,33] (in millions of Btu) to arrive at an annual state oil consumption estimate in Btu for the residential sector. These total oil consumption estimates are allocated first, to the reported state sales of kerosene and the remainder to distillate oil sales. With this approach, any distillate oil remaining after being allocated to the residential sector is assumed to be used by the commercial sector along with the residual oil sales reported for the particular state.

Only oil space heating is assumed to vary by housing type as well as region. Table 7 gives annual fuel consumption in barrels of distillate oil for space heating by 5 housing types and 4 census regions. These figures are further broken down on the state level by multiplying them by the ratio of 1970 state HDD to regional HDD.

Cooking and water heating by oil are given energy use values developed by Dole:[32] 27.2×10^6 and 9.5×10^6 Btu's respectively (the water heating value is multiplied times a regional factor adjusted on a state basis by a HDD ratio to account for inlet water temperature differences).

The results of this analysis in Table 11 show a wide variation of oil use in the residential sector. States located in the south central U.S. have their estimated yearly residential oil use by the above procedure to be less than even their reported sales of kerosene. These states have relatively large agricultural uses of kerosene, primarily crop drying, which could account for this disparity. In addition, the ratio of distillate oil sales to kerosene sales in these south central states is 0.74 whereas for the U.S. the ratio is 7.08. Since no data is available regarding agricultural uses of kerosene in 1970, it is assumed that one-third of the estimated residential oil use is kerosene (with the remainder of kerosene assumed to be used for agricultural purposes) and two-thirds of estimated residential oil use is distillate (with the remainder of distillate in that state assumed to be used by the commercial sector). This assumption is not serious for the estimation of the fuel choice model since distillate as well as residual fuel oil use in the south central states account for less than 2.5% of the U.S. total for those fuels. Twelve other states (two in New England, six in the

Table 11. Household and commercial oil use: 1970

State	Total	Household		Commercial		Percent Distillate used in the commercial sector
		Kerosene	Distillate	Distillate	Residual	
		(10^{10} Btu)				
1 MA	51296.5	907.2	17045.4	14064.2	19279.7	45.21
2 RI	6024.0	214.9	2845.5	1515.7	1447.9	34.75
3 CN	14789.2	322.1	9956.7	1519.8	2990.7	13.24
4 VT	3378.0	284.1	1703.1	1141.8	249.0	40.14
5 NH	5155.3	414.5	2927.6	1133.6	679.6	27.91
6 ME	8417.7	994.0	4556.9	1046.2	1820.7	18.67
7 NY	95437.5	3670.8	49132.9	5064.6	37569.2	9.34
8 PA	35379.2	2169.9	16394.6	8295.8	8518.9	33.60
9 NJ	38341.1	767.7	15960.6	12674.5	8938.2	44.26
10 OH	12053.2	2550.4	4878.2	4316.5	308.1	46.95
11 MC	17299.9	1130.0	9713.0	5826.9	630.0	37.50
12 IL	23404.8	1317.7	7215.6	5852.3	9019.3	44.78
13 IN	12312.7	1172.0	5821.2	3862.9	1456.7	39.89
14 WI	13608.2	1614.2	9342.3	2045.0	606.7	17.96
15 MO	4913.2	294.3	1286.7	2226.3	1105.9	63.37
16 IO	4287.6	191.6	2821.4	1173.9	100.6	29.38
17 MN	10086.8	901.0	7430.2	1131.4	624.3	13.21
18 KA	567.5	85.6	83.8	252.9	145.2	75.10
19 NB	1670.6	305.6	346.8	936.4	81.7	72.97
20 SD	1610.5	7.9	1394.8	198.4	9.4	12.45
21 ND	1818.2	107.7	1492.1	175.0	43.4	10.50
22 DL	2484.3	237.0	1434.2	487.5	325.7	25.37
23 MD	12045.6	1281.4	7270.6	170.3	3323.3	2.29
24 DC	7008.2	23.2	1583.1	191.8	5210.0	10.80
25 WV	712.2	167.3	174.0	18.3	352.7	9.52
26 NC	14446.1	5922.9	3543.8	4153.3	826.1	53.96
27 SC	3974.9	1221.9	2076.4	516.9	159.7	19.93
28 VA	11275.9	2685.9	7034.8	517.9	1037.4	6.86
29 GA	2518.7	108.9	499.6	737.1	1173.2	59.60
30 FL	5026.1	1462.9	382.1	2132.8	1047.4	84.77
31 AL	477.9	68.6	137.3	223.0	49.0	61.90
32 KY	1714.6	410.5	821.0	410.1	72.9	33.30
33 TN	1381.3	315.6	631.1	425.2	9.4	40.30
34 MS	445.4	11.5	23.1	380.0	30.8	94.30
35 TX	1921.7	34.6	69.1	1469.7	348.3	95.50
36 AR	302.0	15.7	31.5	254.8	0.0	89.00
37 LA	424.2	17.8	35.5	360.8	10.1	91.00
38 OK	375.7	7.9	15.8	311.1	40.9	95.20
39 AZ	84.9	7.2	14.4	54.5	8.8	79.10
40 NM	197.0	24.0	48.0	123.1	1.9	71.90
41 CO	1141.8	211.5	23.0	692.9	214.4	96.79
42 MT	757.3	53.3	479.0	109.9	115.1	18.66
43 WY	606.3	22.0	44.1	326.4	213.8	88.10
44 UT	1192.2	71.4	118.9	581.9	420.0	83.03
45 NV	490.4	5.7	173.7	285.9	25.1	62.22
46 ID	1881.6	65.8	1415.7	326.0	74.2	18.72
47 CA	2390.1	96.2	192.4	603.3	1498.2	75.80
48 OR	5809.2	72.6	3161.0	496.6	2079.1	13.58
49 WA	9344.0	76.0	6170.8	752.8	2344.4	10.87
50 US	452281.5	34122.5	209953.9	91567.9	116637.1	30.37

east and west north central regions and four in the upper mountain and pacific regions) use almost all of the kerosene and distillate for residential uses. The commercial sector in these states were using mainly residual fuel oils in 1970. The household sector in the remaining twenty-six states consume all of the kerosene reported sold for heating purposes by the Bureau of Mines and a fraction of the distillate fuels varying from 14% for Florida to 91% for New York.

This analysis for 1970 shows a slightly smaller fraction of distillate oils used in the commercial sector (30.4%) than the 35% reported in the 1976 *National Energy Outlook.*[18] This could be due to our inclusion of oil appliances in addition to oil furnaces in the fuel oil usage calculations. As with the electricity and natural gas consumption data series, the fraction of distillate calculated for each state using 1970 data is applied to all years of the oil consumption data series (1967 through 1972).

Table 11 shows oil use for 1970 in the residential and commercial sectors calculated by the above procedure. Column 3 gives total oil use in both residential and commercial sectors (kerosene, distillate and residual oils). Columns 4 and 5 give residential consumption of kerosene and distillate oils. Columns 6 and 7 give the commercial sector use of distillate and residual fuel oils. Column 8 gives the percentage of distillate oil used in the commercial sector.

Appendix B

Procedure for calculating state level commercial stock of floor space from 1968 to 1972

Floor space values for office buildings, retail and wholesale, public buildings, garages, warehouses, religious buildings, and miscellaneous buildings were based mainly on floor space per employee[35] for each of these subsectors. For hotels and motels, the state floor space estimates are based primarily on number of hotel-motel rooms. The ORNL commercial models' hotel-motel floor space estimate for the U.S.[1] is multiplied by the state to U.S. ratio of hotel-motel rooms to estimate the number of hotel-motel rooms at the state level. Calculation of the floor space in the health subsector uses a combination of Ide floor space per employee estimate and ORNL floor space per hospital bed estimates.

Floor space was calculated for elementary and secondary school buildings, higher education buildings, and other service buildings to obtain a total for the education subsector.[36,37] All commercial subsector floor space calculations for 1970 are based on control totals for the U.S. developed in the ORNL commercial sector engineering-economic model.[1] Since only the total commercial floor space for each state is used in this analysis as an explanatory variable, all ten commercial subsector floor space values are summed.

Again, the above description pertains only to 1970 commercial floor space stock estimates. To develop time series estimates of commercial floor space by state entails a calculation of state additions to floor space for the years 1968 to 1972.

The data used are:

(1) $TV_{i,t}$ — valuation of total private nonresidential construction — commercial and industrial sectors (in millions of dollars),

(2) $ME_{i,t}$ — manufacturing employment (in thousands),

(3) $I_{k,t}$ — valuation of industrial buildings construction (in millions of dollars),

(4) $DI_{j,t}$ — F. W. Dodge regional index of valuation,

(5) FLD_t — F. W. Dodge U.S. additions to floor space for year t (millions of ft^2).

i refers to state, j refers to the F. W. Dodge regions and k refers to the 4 U.S. regions (NE, NC, S, and W). Valuation of new industrial construction for each state, $I_{i,t}$ can be approximated as the regional valuation of industrial construction times the ratio of state manufacturing employment to regional manufacturing employment.

$$I_{i,t} = I_{k,t} \cdot \frac{ME_{i,t}}{\sum_i^k ME_{i,t}}$$

Commercial sector floor space added for state i and year t, $AFL_{i,t}$, can now be estimated by subtracting the state industrial valuation of added floor space ($I_{i,t}$) from the total valuation of added floor space ($TV_{i,t}$) and dividing the result by the F. W. Dodge regional index of valuation, $DI_{i,t}$. (An assumption is made to give states within one of the eight F. W. Dodge regions, that particular region's index of valuation.) So,

$$AFL_{i,t} = \frac{TV_{i,t} - I_{i,t}}{DI_{j,t}} .$$

To adjust the calculated additions to floor space ($AFL_{i,t}$) to the U.S. total commercial floor space additions for year t, the following calculation is made:

$$Fl_{i,t} = FLD_t \cdot \frac{AFL_{i,t}}{\sum_{i=1}^{50} AFL_{i,t}}$$

Using the following procedure, the 1970 state commercial stock of floor space is then adjusted by the calculated state additions of floor space for 1968 through 1972 to arrive at state level stock of floor space values for 1968 through 1972.

A calculated decay rate is applied to all states' existing stock of floor space such that when the additions to floor space are added to the existing stock, the sum of the state floor space stock values for each year equal the U.S. total commercial stock of floor space as developed in the previous ORNL commercial sector study.[1] These adjustments to the existing state level stock ($S_{i,t}$) and their additions, $Fl_{i,t}$, for each year are as follows:

$$S_{i,69} = (S_{i,70} - Fl_{i,70}) \cdot e^{0.00837}$$

$$S_{i,68} = (S_{i,69} - Fl_{i,69}) \cdot e^{0.006631}$$

$$S_{i,71} = S_{i,70} \cdot e^{-0.007232} + Fl_{i,71}$$

$$S_{i,72} = S_{i,71} \cdot e^{-0.006704} + Fl_{i,72}$$

where $S_{i,70}$, the state level stock of floor space for the base year 1970, is described previously.

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