AN ANALYSIS OF HEATING AND COOLING CONSERVATION FEATURES IN COMMERCIAL BUILDINGS

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One purpose of this study is to estimate the relationship in commercial buildings between conservation investments, fuel prices, building occupancy and building characteristics for new buildings and for existing buildings. The data base is a nationwide survey of energy in commercial buildings conducted by the Energy Information Administration (EIA) in 1986. Some simple cross-tabulations indicate that conservation measures vary with building size, building age, type of building, and fuel used for building heating. Regression estimates of a conservation model indicate that the number of conservation features installed during construction is a positive function of the price of the heating fuel at the time of construction. Subsequent additions of conservation features are positively correlated with increases in heating fuel prices. Given the EIA projection of relatively stable future energy prices, the number of retrofits may not increase significantly. Also, energy efficiency in new buildings may not continue to increase relative to current new buildings. If fuel prices affect consumption via initial conservation investments, current fuel prices, marginal or average, are not the appropriate specification. The fuel price regression results indicate that conservation investments in new buildings are responsive to market signals. Retrofits are less responsive to market signals. The number of conservation features in a building is not statistically related to the type of occupancy (owner versus renter), which implies that conservation strategies are not impeded by the renting or leasing of buildings.

INTRODUCTION

The Energy Information Administration (EIA) annually prepares long-term forecasts of energy consumption by sector. The projections of energy use in the commercial sector reflect the estimated energy intensity of commercial buildings which, in turn, depend on the conservation features of these buildings. The conservation features of commercial buildings are also of interest to the U.S. Department of Energy's (DOE) Office of Conservation and Renewable Energy, because this Office is responsible for the energy policies that recommend efficiency standards in commercial buildings and appliances. The focus of the present study is on the relationship between conservation features in commercial buildings, fuel prices, building occupancy and building characteristics.

The data base used in this study is a 1986 nationwide survey of energy use in commercial buildings conducted by the EIA (EIA 1988). This survey includes a series of questions about energy conservation measures in commercial buildings. These data are used to construct a profile of the commercial buildings according to the conservation features contained in these buildings. Cross-tabulations depict the frequency of these conservation features by selected building characteristics, including size, building activity, age and fuel used for heating. A conservation model is developed to explain the number of conservation features that characterize existing buildings. The implications of the results are discussed in the final section.

Regression estimates of a conservation model indicate that the number of conservation features installed during construction is a positive function of the price of heating fuel at the time of construction. Subsequent retrofits of conservation features are positively correlated with increases in heating fuel prices. In an EIA base-case scenario of near-constant future electricity prices and in the absence of mandatory standards, the number of conservation measures contained in future constructed buildings is not likely to exceed that of current new buildings. Commercial buildings are also unlikely to engage in extensive additional retrofitting in the future. However, the stock of commercial buildings will contain an increasing number of conservation measures over time simply because newly constructed buildings contain more conservation features than the average of the total stock and of buildings being retired.

CONSERVATION MEASURES AND BUILDING CHARACTERISTICS

A profile of building conservation features is presented by cross-tabulating conservation features with building characteristics. One purpose of these tabulations is to convey an understanding of the frequency and type of conservation features that characterize commercial buildings. This information is then used to specify a conservation demand model. The very important distinction is made between conservation measures installed at the time of construction and subsequently added as a retrofit. The building characteristics include year of construction, building type (or activity), building size and fuel used for heating.

The primary data base for this study is the 1986 Nonresidential Buildings Consumption and Expenditures (NBECS) survey by the EIA (1988). In this survey, conservation activities are divided into three categories: shell efficiency, heating, cooling and ventilation (HVAC), and lighting. The present study is limited to shell and HVAC measures. Within each of these categories, data were obtained for five to seven specific conservation activities. For instance, the building manager was asked whether the building was characterized by each of seven measures of building shell efficiency and comparable questions were asked for each HVAC and lighting conservation measure. When the response was affirmative, the first follow-up question was whether the conservation measure was taken at the time of construction or whether it was a retrofit. If the measure was added after construction, the follow-up question determined if the conservation measure was added in 1986, between 1980 and 1985, or before 1980. The data base reflects responses to several questions about each of 13 different conservation features and more than 6000 buildings. The cross-tabulations reflect the frequency of 7 shell efficiency measures and 6 HVAC measures with each of four building characteristics. (The data tables are available from the author.)

Conservation measures are first cross tabulated with buildings by year of construction. The most frequently observed conservation features of commercial buildings relate to shell efficiency, such as roofing/ceiling insulation, wall insulation and weather stripping, each of which is present in more than half of the sample of commercial buildings. Newer buildings are more likely to have roofing or ceiling insulation than older buildings. The trend is quite striking because the percent of buildings increases consistently from 53.9% of the pre-1946 buildings to 86.1% of the buildings constructed after 1980. A similarly increasing trend characterizes the other shell efficiency conservation measures, including HVAC measures.

Conservation measures installed during construction occur with much higher frequency in newer buildings than older buildings. Only 19.8% of the pre-1946 buildings had roof or ceiling insulation installed during construction, but 83.5% of the buildings build after 1980 installed such insulation. Newer buildings are more likely to have each of the shell efficiency features and to have installed them at the time of construction.

The percent of commercial buildings that added each conservation measure after construction varies inversely with newness. Only 2.7% of the buildings built after 1980 had roofing or ceiling insulation added after construction, whereas 34.2% of these buildings built before 1946 subsequently added this insulation. This inverse relationship between building age and percent of buildings that have been retrofitted also applies to the other shell efficiency features and HVAC features. The buildings constructed after 1980 have subsequently added almost no conservation features via retrofit.

Cross-tabulations are constructed for conservation measures and the following building types: warehouse, retail/wholesale, office, education, continuous use and other buildings. The results indicate that office buildings are more likely to be characterized by each type of conservation measure than any other building. These measures are typically installed in office buildings initially and not added after construction.

The cross-tabulations between building size reveal that the frequency of each conservation measure, for both shell and HVAC, increases as building square footage increases. This positive association is particularly strong when the conservation measure is installed during initial construction, but it also holds for "added" conservation measures in all but two cases. The percent of buildings that add wall or roof/ceiling insulation does not increase with building size, but each of these conservation measures is initially installed in a very high percent of buildings. The general conclusion remains: the larger the building, the greater the probability that it contains the various conservation measures.

The main heating fuel used in commercial buildings is generally natural gas, electricity or fuel oil. The choice of heating fuel is correlated with various conservation measures. Buildings that heat with electricity are more likely to have undertaken each conservation action than buildings that heat with the fossil fuels. There is also a tendency for buildings that heat with natural gas to have more conservation features than those that heat with oil.

In sum, the cross-tabulation analysis yielded the following conclusions: (1) Newer buildings are more likely to contain each particular conservation measure, installed during construction, than older buildings; (2) Older buildings are more likely to contain conservation features that were added after initial construction than newer buildings; (3) Larger buildings are more likely to contain each particular conservation measure than smaller buildings; (4) Office buildings are more likely to include conservation measures than any other building; (5) Buildings that heat with electricity are more likely to contain the shell efficiency measures than buildings heated with gas or oil; (6) Conservation measures are generally undertaken jointly. For instance, buildings that have roofing or ceiling insulation are twice as likely to have other shell efficiency measures as buildings that do not have such insulation.

Four building characteristics have been cross-tabulated with conservation measures and discussed as if these characteristics were independent. In fact, the newer the building, the more likely it is to be heated with electricity and to be an office building. Also, buildings built after 1970 are, on average, larger than buildings constructed before 1960s. The four building characteristics that we find correlated with the frequency of conservation measures are also correlated with each other. Large, new, office buildings heated with electricity are more likely to contain shell efficiency, HVAC and lighting conservation measures than are other buildings. Interestingly, these buildings are typically more energy intensive than other buildings.

A CONSERVATION MODEL

The above cross-tabulations depict a statistical association between various building characteristics and the frequency of conservation features. However, the underlying causal relationships are unspecified. A model of conservation is now developed to explain and predict the number of shell efficiency and HVAC measures in existing and future commercial buildings. Separate models are estimated for conservation measures "installed" during construction and those "added" after construction.

The dependent variable is the number of shell efficiency features plus HVAC conservation features contained in each building. Conservation features are admittedly not homogeneous nor additive in the sense of contributing to energy efficiency. However, buildings that contain numerous conservation features are assumed to reflect a greater effort towards energy efficiency than buildings without such features.

The building characteristic variables are hypothesized to be separate causal variables and are therefore included as independent variables. Five dummy variables are used to reflect the six building activity categories. The model also includes building size as measured by square feet, because the above data showed this variable to be associated with conservation measures. Buildings that use electricity, natural gas or fuel oil as their main heating source are identified by a zero-one dummy variable. The year of construction is not included because it is simply a time trend.

The conservation literature has found consistently that rented or leased buildings are less likely to contain conservation features than owner occupied buildings (Karnitz 1986; OTA 1982). This view is accepted by the DOE (1990) who notes that building owners simply pass energy costs directly to tenants and building developers try to minimize first costs rather than life-cycle costs. The occupancy hypothesis is tested with a dummy variable, where owner occupied buildings were denoted with a one, otherwise with a zero. The hypothesis implies that positive and significant regression coefficients be observed for both installed and added conservation measures.

If a building is constructed to meet heating and cooling loads at minimum life-cycle costs, then higher fuel prices encourage an increase in both shell and HVAC efficiencies. The price of the main heating fuel is the appropriate energy price, because both shell and HVAC measures have their main effect on heating loads. The number of installed HVAC and shell features should be positively associated with the present value of expected heating fuel prices; however, fuel prices at the time of construction are used. Higher fuel prices also encourage the adoption of energy efficient building codes as well as conservation policies.

EIA fuel price data by state and by year were used to obtain Census Division fuel prices for each year after 1970. Individual buildings in the survey are identified as being in one of the ten Census Divisions. The absence of fuel price data before 1970 limits the sample of buildings to those constructed after 1970.

A separate but similar model is used to estimate building conservation measures installed after initial construction. When a building is constructed, it should be energy efficient relative to prevailing and expected heating and cooling fuel prices. If fuel prices rise significantly above those expected at initial construction, then retrofitting may become feasible. The appropriate fuel-price specification for a retrofit model is probably the current price relative to the fuel price at the time of initial installation. The larger this price differential, the more conservation features we expect to observe in commercial buildings. Energy-market conditions in the early 1980s were similar to current conditions, but conditions prior to 1960 were very different from those today. Retrofitting older buildings that were constructed when energy prices were low is more feasible than retrofitting buildings that were designed during near-present conditions. We hypothesize that the number of conservation features "added" to a building is a positive function of the heating fuel price differential between current and initial fuel prices.

The conservation model estimates the number of HVAC and shell conservation features in a building as a linear function of building size, building activity, building occupancy and price of main heating fuel. The regional price of electricity, natural gas and fuel oil was multiplied by one-zero dummy variables that identified the type of main heating fuel. In this way, the effect of fuel prices on conservation features is estimated, conditional that the fuel was used for space heating. Dummy variables were also included to allow the fuel price relationship to take on a different intercept for each fuel. Conservation equations were estimated separately for installed and added conservation features, but the models differed only in the specification of the price variable, as discussed above. The Chow test (Maddala 1977) indicated that the model has different slopes and intercepts across the four Census Regions; therefore, the model is estimated on a regional basis.

Regression estimates of the "installed" and "added" conservation models are presented in Tables 1 and 2. Two fuel prices are significantly associated with

Table 1. Regression Estimates of "Installed" Conservation Measures in Commercial Buildings

Variable	Census Regions Northeast	Midwest	South	West
Intercept	1.85	3.29	2.95	4.08
	(2.30)	(3.20)	(4.94)	(2.32)
Price				
Electricity	0.13	0.29	0.28	0.47
	(1.39)	(2.51)	(6.90)	(7.85)
Natural gas	0.66	0.71	0.48	0.75
	(4.13)	(7.52)	(9.78)	(9.16)
Fuel oil	0.49	-0.13	0.22	-0.18
	(3.49)	(-0.35)	(1.57)	(-0.42)
Dummy Variable-	-0.55	-4.93	-3.08	-6.67
Electric Heat	(-0.24)	(-2.03)	(-3.41)	(-3.54)
Dummy Variable-	-0.46	-2.16	-0.10	-2.18
Natural Gas Heat	(-0.46)	(-1.70)	(-0.16)	(-1.24)
Area (ft^2)	1.73	2.23	2.12	2.88
	(3.99)	(4.87)	(9.06)	(5.51)
Occupancy	-0.28	-0.10	-0.08	0.22
(owner/renter)	(-0.91)	(-0.52)	(-0.55)	(1.17)
Building Type				
Warehouse	-0.52	-0.22	-0.89	-1.50
	(-1.14)	(-0.75)	(-3.69)	(-5.00)
Retail/Whole.	-0.74	-0.43	-0.58	-0.88
	(-1.98)	(-1.03)	(-3.10)	(-3.19)
Education	1.02	0.38	-0.39	-0.40
	(1.47)	(0.88)	(-1.27)	(-0.96)
Office	1.75	1.45	0.87	0.16
	(4.32)	(5.49)	(4.40)	(0.65)
Continuous use	0.15	0.46	0.27	0.24
	(0.30)	(1.10)	(2.75)	(0.64)
R^2	0.33	0.27	0.31	0.34
Sample	256	479	790	490

Notes: Numbers in parentheses are t values. R^2 = coefficient of determination.

Table 2. Regression Estimates of "Added" Conservation Measures in Commercial Buildings

Variable	Census Regions Northeast	Midwest	South	West
Intercept	0.73	0.62	0.84	0.24
	(2.08)	(1.82)	(5.11)	(0.51)
Price				
Electricity	0.05	0.15	0.11	0.16
	(0.69)	(1.74)	(4.30)	(5.09)
Natural gas	0.22	0.41	0.28	0.35
	(1.69)	(6.43)	(6.10)	(7.53)
Fuel oil	0.20)	-0.34	0.06	0.24
	(1.83)	(-0.86)	(0.66)	(0.52)
Electric Heat	-0.11	0.04	-0.34	-0.03
	(-0.38)	(0.11)	(-2.20)	(-0.07)
Dummy Variable-				
Natural Gas Heat	-0.03	-0.06	-0.31	0.10
	(-0.10)	(-0.18)	(-1.94)	(0.22)
Area (ft^2)	6.74	7.92	1.24	6.29
	(1.96)	(2.70)	(0.94)	(2.15)
Occupancy	0.22	0.06	-0.06	-0.03
(owner/renter)	(0.90)	(0.49)	(-0.83)	(0.24)
Building type				
Warehouse	-0.52	-0.36	-0.27	0.34
	(-1.45)	(-1.93)	(-1.96)	(-2.01)
Retail/Wholesale	0.01	-0.01	0.05	0.15
	(0.05)	(-0.07)	(0.47)	(0.96)
Education	0.87	-0.06	0.07	0.37
	(0.87)	(-0.22)	(0.41)	(1.60)
Office	-0.39	-0.18	-0.01	0.26
	(-1.22)	(-1.05)	(-0.07)	(1.90)
Continuous use	1.44	0.64	0.22	0.14
	(3.63)	(2.43)	(1.51)	(0.68)
R^2	0.16	0.14	0.10	0.19
Sample size	256	479	790	490

Notes: Numbers in parentheses are t values. R^2 = coefficient of determination.

the number of installed conservation features in each of the four regions, although the fuels differ across regions. In the Northeast, conservation features are associated with the price of fuel oil and natural gas, whereas in the other regions electricity and natural gas are the significant prices. This result is reasonable because fuel oil is a main heating fuel in the Northeast; by contrast, other regions rely on natural gas and electricity. The square-feet variable is significant in three regions and confirms the cross-tabulation result that more conservation features are installed in larger buildings. Office buildings are statistically associated with the number of conservation features in each region except the West, where continuous-use buildings appear important. The building occupancy variable is insignificant in each of the four regions, which implies that owner occupied buildings do not contain more installed conservation measures than other buildings.

The regression estimates of the conservation model of "added" conservation features are listed in Table 2. As expected, the fuel price coefficients are again positive, and the fuel oil price coefficient is significant only in the Northeast and electricity is significant in the other three regions. The number of conservation features added to buildings is positively associated with the incremental increases in natural gas prices in each of the four regions. In this model, continuous-use buildings are positively associated with conservation features in three regions, and office buildings only significant in the West. We again observe that larger buildings are associated with more conservation features, but the association is not as strong as in the installed model. We also observe that owner occupied buildings are not statistically related to retrofit conservation features.

The most important result in these two tables is the positive and significant relationship between heating fuel prices and conservation features. However, the association is much stronger with conservation features installed during the construction of commercial buildings than those added after construction. The magnitude of the regression coefficients is greater for the installed model, the "t" values are consistently larger and the overall explanatory power of the model is also greater. The mechanism by which fuel prices affect consumption includes conservation features, both installed and added. Of these two effects, the largest response appears to be conservation features installed in newly constructed buildings.

The R^2 values in the "installed" table average about 0.30 and in the retrofit table they average about 0.15. The explanatory power of cross section models is typically low, especially when the data do not include a scale effect. The low R^2 values are a consequence of noisy data and important variables omitted from the model. If data were available, conservation investments should also be related to building codes, utility demand side management programs, as well as conservation investment and transactions costs. The regression estimates document that several variables are statistically related to conservation measures, but much of the variation in remains unexplained.

IMPLICATIONS

To the extent that the conservation linkage constitutes an important component in the overall fuel price effect, it suggests that the distributed lag effect of fuel price changes is very long and does not follow a partial adjustment mechanism. A one time, permanent increase in a fuel price should increase the number of conservation features installed in new buildings and this effect (elasticity) could be a constant that continues indefinitely as new buildings are added to the stock each year. Existing buildings will add conservation features as a result of the fuel price rise, and the path of this adjustment could decline geometrically. However, the regression results imply that conservation features are more likely to be installed in new buildings than added to existing buildings.

An important issue in the energy demand literature is whether the fuel price should be measured as an average or marginal price. Following Lester Taylor (1975), most researchers have argued on behalf of marginal prices. When a price response is short-term, such as adjusting a thermostat, the marginal price could be the appropriate decision variable. However, conservation measures considered here respond to initial fuel prices and their subsequent changes and not to current prices--marginal or average.

An energy demand model should be specified to reflect the mechanism by which fuel prices affect fuel use. First, relative fuel prices affect the probability that a given fuel is selected for heating or cooling needs (Sutherland 1990). Given that a fuel is selected, its absolute price influences the efficient choice for shell efficiency and HVAC measures. Fuel price changes subsequent to construction influence the feasibility of retrofit measures. Fuel prices can also affect conservation investments indirectly by encouraging the adoption of building codes or utility demand side management programs. Current fuel consumption reflects investment choices made previously on the basis of past fuel prices. The dominant effects of fuel prices on consumption are probably embodied in the capital stock, and the effects of current prices (marginal or average) on current consumption are much weaker.

The statistical association between four building characteristics and conservation features appears innocuous, but raises an interesting modeling issue. A conservation investment model should account for the statistical association between conservation features and building characteristics. A simple model could apply to various building characteristics. For instance, if information costs decrease relative to building size, conservation investments become more cost effective with large buildings. However, if such investments are causally related to building characteristics, then the analysis must reconcile modern investment theory with these characteristics.

Conservation investments in new buildings are more sensitive to fuel prices than are retrofits, in part, because of lower transactions costs. Energy design and technology choices in new buildings are made by professionals who make these decisions quite frequently. Energy efficiency information is widely available and decision-makers have an incentive to obtain this information. A building owner contemplating a retrofit may have negligible personal expertise and find relevant information expensive to obtain. The retrofit market is relatively insensitive to fuel prices partially because of information costs; hence this market is probably insensitive to other market signals, such as taxes, rebates and subsidies, as well.

Buildings that contain numerous conservation features are much more likely to have them installed during construction than added as a retrofit. This result holds for each age category, except for buildings constructed prior to 1946. If we assume these conservation features to reflect an equilibrium, then the economically efficient investment in conservation features is greater in new buildings than in comparable existing buildings. Conservation strategies that rely on market incentives probably achieve a higher level of energy efficiency in new buildings than in existing buildings.

The lack of a statistical association between owner-occupancy and conservation may, at first seem surprising. Modern investment theory implies that cost-effective energy investments will be undertaken and will be impervious to occupancy. The building owner can increase the rent sufficient to pay for the investment and still reduce rent plus energy costs to the tenant. Certainly, the lessee will accept an increase in rent if compensated by a greater reduction in energy costs. The benefits of cost-effective conservation investments can easily be shared; hence the incentives for energy efficient investments are the same is owner-occupied buildings. To the extent that potential renters are unaware of energy costs, or that energy costs are unimportant, some leased buildings could be less energy efficient than an identical building that is owner occupied. However, this result is not observed statistically.

The EIA (1989) projects the price of energy in the commercial sector to increase at an annual rate of 1.3%/yr through the year 2000, with the price of electricity declining slightly. With these price projections, the above conservation model implies that the number of conservation features embodied in future new buildings is not likely to exceed that of current vintage buildings. Few conservation features are likely to be added to currently existing buildings because the increment (current minus initial) in fuel prices is not projected to increase. The stock of commercial buildings will become more energy efficient over time because new buildings are more efficient than the average of the current stock.

The potential reduction in energy consumption in existing commercial buildings has been estimated in numerous studies to be in the range of 40-50% (MacDonald 1986; OTA 1982). However, the fuel price regression results imply that retrofit investments are not highly sensitive to market signals. Considering that currently existing buildings will remain a large share of the total building stock for at least a few decades, achieving energy efficiency improvements in the building sector is indeed a challenge. A useful next step is to apply modern finance principles to better understand the investment process in energy conservation.

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