DO ENERGY RETROFITS WORK?
EVIDENCE FROM COMMERCIAL AND RESIDENTIAL BUILDINGS IN PHOENIX

Jing Liang, School of Sustainability, Arizona State University. Wrigley Hall, 800 Cady Mall #108, Tempe, AZ 85281. 480-434- 0138 Liang.Jing.2@asu.edu

Yueming Qiu. Technological Entrepreneurship and Management Program, Arizona State University. Sutton Hall Suite 340M, 6049 S Backus Mall, Mesa, AZ 85212. 480-727-4097 yueming.qiu@asu.edu

Overview

Buildings are a major component of energy use, accounting for 40% of total energy consumption and 60% of electrical usage in developed nations (Fernandez, 2007). Energy efficiency is recognized as a key method to reduce energy consumption and the associated carbon emission of buildings (Bouton et al., 2010). To date, there are numerous energy-efficiency upgrade programs supported by the federal government, as well as at the state, local, and utility levels. Discrepancy exists between realized energy savings and the estimated savings predicted by engineering models. There are many possible explanations for this deviation including technology instability, occupant behavior problems, and modeling or measurement inaccuracies (Gillingham and Palmer, 2013). One of the factors is the rebound effect (Scheer et al., 2013). Estimating the realized savings of adopting energy-efficiency retrofits has become critically important given that results can be highly valuable to policymakers and building owners in making their energy efficiency related decisions.

The amount of energy saved from retrofits in practice varies across measures and locations. One limitation of existing economics studies on weatherization programs is that past studies mainly focus on low-income families rather than moderate- and high-income homeowners. In addition, few empirical studies have been conducted in the arid Southwestern U.S. Besides, energy savings of retrofits in commercial buildings based on large samples are rarely analyzed in existing literature (Kahn et al., 2014), and large pre-post treatment field studies incorporating occupant behavior and market-standard contractor work are equally rare.

Our study adds to existing literature in two aspects. First, we provide empirical assessment of energy savings following retrofits in commercial buildings. Second, for residential buildings, we also analyze moderate- and highincome homeowners. We use monthly billing data for commercial and residential buildings to evaluate the effects of overall retrofits, individual retrofits and retrofit bundles.

Methods

The data is obtained from the Energize Phoenix program, which is an energy efficiency program led by a joint collaboration of major institutions, including the City of Phoenix, Arizona State University, and Arizona Public Service (the state's largest electricity provider). The residential buildings were divided into three programs: Energy Assist 60/40 (moderate income), Energy Assist 100% (low income) , and Rebate Match (higher income). The program spans January 2008 through April 2013. There are 201 residential buildings for a total of 10,235 observations and 636 commercial buildings for a total of 35,681 observations. The retrofits encompass five types of retrofits for residential buildings (upgrades in air conditioner, insulation, duct sealing, air sealing, and shade screens) and six types for commercial buildings (upgrades in heating, ventilation, and air conditioning (HVAC), light bulbs and fixtures (lighting), refrigeration, pumps or motors, lighting controls, and windows). Each residential or commercial building could adopt a combination of retrofits (bundle). To estimate the overall treatment effects, fixed effects is employed by regressing energy use onto retrofits and other variables:

$$In(Energy_{it}) = \alpha T_{it} + \beta P_{it} + \delta_1 CDD_t + \delta_2 HDD_t + \eta_i + \xi_t + \varepsilon_{it} \quad (1)$$

where *Energy* is the monthly energy use (*kWh*); *i* indicates an individual building; *t* indicates the month; T_{it} equals one if the building has received any treatment at time *t* and zero otherwise; P_{it} is the electricity price; δ_1 and δ_2 reflect the effects of temperature on electricity use; η_i is individual building fixed effects controlling for any unobservable attributes of buildings that do not change over time; ξ_t is monthly fixed effects controlling for factors that influence all buildings at the same time. With this model specification, we also explore the impacts of retrofits by season, which is whether the impacts are influenced by time of installation by separating all the observations into winter (November to April) and summer (May to October) seasons.

To disentangle the effect of each type of retrofit, the model specification is made as:

$$In(Energy_{it}) = \boldsymbol{\alpha}' \boldsymbol{T}_{it} + \beta P_{it} + \delta_1 CDD_t + \delta_2 HDD_t + \eta_i + \xi_t + \varepsilon_{it} \quad (2)$$

where $\boldsymbol{T}_{it}$ is the vector of treatment dummy variables, including five for residential buildings, and six for commercial buildings. This specification is also applied at the same time for bundles analysis. New dummies are generated for different bundles.

EUI (kWh/sqft) is obtained by dividing energy consumption by the total area of the building. For all the previous model specifications with *In*(*Energy)* as dependent variable, there are corresponding models for EUI as dependent variable. To assess the impacts of building attributes on the effects of retrofits, interaction terms between retrofits and building attributes are added. To control for time-variant individual factors, such as changes in financial status and environmental awareness, which influence both the selection of treatments and energy consumption, individual-year flexible fixed effects η_{iy} are used. Meanwhile, to examine the learning effects, we also introduce interaction terms $T_{it}L_{it}$ and $T_{it}L_{it}^2$ into model.

Results

For commercial buildings, the average monthly energy savings are 12.0%. For residential buildings, the retrofits reduce the monthly energy use by 7.2%. In the Energy Assist 60/40 program, the retrofits reduce monthly energy use by 26.3% while energy savings are not seen for the Energy Assist 100% program and Rebate Match program (P>0.10). This indicates that the middle-income households exhibit the largest energy saving rather than the low-income and higher-income households.

The impacts of each type of retrofit are different. An upgrade in insulation significantly decreases energy consumption by 42.1% for the Energy Assist 60/40 program. Air sealing reduces energy use by 9.8% for the Rebate Match program. In addition, the retrofits in HVAC and pumps are significant in reducing energy use by 21.1% and 22.0% for commercial buildings. Upgrades in lighting and windows are significant in saving energy by 9.9% and 17.6%. Other types of energy retrofits are insignificant (P > 0.10).

The impacts of retrofit bundles on three residential programs are different. Only the bundle of insulation & duct sealing & air sealing & shade screens is statistically significant in reducing energy use by 8.3% for all residential buildings. For commercial buildings, the bundle of lighting & refrigeration has the most impact on the reduction of energy use.

EUI for residential buildings in the Energy Assist 60/40 program decreases by 23.8% per month, while EUI for commercial buildings reduces by 13.1%. The negative signs of coefficients on the interaction terms suggest that the effects of retrofits were more pronounced if initial building conditions were poorer. Consumers are more likely to save energy during the winter season than summer season. This could be due to the extremely hot climate in Phoenix when AC use is a necessity. Learning effects do exist, though the magnitude of the coefficients on the interaction terms of retrofit and learning effects are not quite large. This means there is a possibility for improved learning and control of energy use for the EP program as the post-retrofit time increases.

Conclusions

This study empirically estimates the net energy savings of adopting retrofits in commercial and residential buildings in Phoenix, Arizona. The overall effects of energy retrofits are 12.0% energy savings for commercial buildings and 7.2% for residential buildings. Residential buildings in Energy Assist 60/40 show statistically significant reduction in energy use, which includes mainly middle-income households, while the Energy Assist 100% program and Rebate Match program do not. The realized energy savings are 30-50% lower than those predicted by engineering models. The gap between the estimated savings and realized savings for residential buildings is larger than that for commercial buildings. Possible explanations for this deviation include the rebound effect, technology instability, and engineering modeling or measurement inaccuracies. There are also learning effects observed in this program, which means as the post-retrofit time increases, there is improved learning and control of energy use, and accordingly there are more energy savings for the buildings. Policy implications include ensuring the retrofit quality through setting up standards, incorporating behavioral responses into policy-making, and incentivizing utility companies to subsidize retrofits that can achieve a significant amount of energy savings.

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