Low hanging fruit? Regulations and Energy Efficiency in Subsidized Multifamily Housing

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Abstract

The U.S. government has invested in multifamily housing through an array of subsidized housing programs. These programs provide a venue for understanding how regulations governing multifamily housing can affect an owner's incentive to make energy efficient investments, and a tenant's desire to reduce their energy consumption levels. This paper empirically tests the impact of subsidized housing regulations on the energy efficiency of multi-family housing for low-income households. We begin by constructing a unique database that integrates actual energy use with physical, socioeconomic, and regulatory characteristics of all large multifamily properties in New York City, focusing on whether a property receives a federal rental subsidy. We employ multivariate regression models to examine the factors that influence energy consumption in multi-family buildings and compare subsidized housing to market-rate housing. We find that subsidized properties are associated with higher energy consumption than similar market-rate properties and, of the subsidized housing programs, Public Housing tends to consume the most energy. Our results suggest that despite the potential for retrofitting multifamily

properties, and associated cost, energy, and carbon emissions savings, regulatory factors constrain investment and consumption decisions in the case of subsidized properties. Reducing energy use in subsidized housing, therefore, rests on modifying existing regulations.

Keywords

Regulations, subsidized housing, utility consumption, energy efficiency, split incentive, metering

1. Introduction

Cities across the globe are implementing plans to reduce greenhouse gas (GHG) emissions, and often cite the retrofitting of existing buildings, and multifamily housing in particular, as one means to achieve this goal. Following the Paris Agreement in 2015 and the United Nations Framework Convention on Climate Change, many cities, including Berlin, Sydney, Yokohama, New York City, and Vancouver, have committed to reducing GHG emissions by 80 percent by 2050. For high-density cities like New York, where buildings represent the largest source of GHG emissions (City of New York 2014) and multi-family housing accounts for more than 40 percent of the 3.25 million residential units across the City (Furman Center 2010), the retrofitting of multifamily housing could be a highly effective way to reduce emissions, energy use, and household utility costs. It is projected that multifamily properties across the country could be approximately 30 percent more energy efficient using existing technologies (Brown et al. 2008; Benningfield Group 2009). For lower income households, the federal government has invested in multifamily housing through an array of subsidized housing programs. In theory, these subsidized properties are “low hanging fruit” for increasing energy efficiency in multifamily housing because the government has regulatory levers to require certain efficiency levels and can create new financing programs targeting these properties. In practice, these programs present an important venue for understanding how regulations governing multifamily units can affect an owner’s incentive to make energy efficient investments, and a tenant’s desire to reduce their own energy consumption levels.

Market failures that lead to a socially sub-optimal investment in energy efficiency have been well-studied (Jaffe and Stavins 1994; Gillingham et al 2009). These market failures include information asymmetries, ineffective pricing signals, environmental externalities, and the split-incentive problem. The split-incentive problem is of particular importance in the multifamily housing context, as it emerges between tenants and owners with respect to who bears the cost of energy efficiency improvement and who realizes the benefits of new savings. This challenge is particularly pronounced in subsidized housing, where rent levels and escalations are typically fixed and landlords are constrained in their ability to capitalize the market value of energy improvements (Fuerst et al. 2015). In addition, energy expenses add to the cost burden of low-income, subsidized housing tenants, which should increase tenant demand for more efficient units, depending on the utility allowance scheme of the particular subsidy program (Hernandez and Bird 2010).

In this paper, we examine the previously unexplored question of whether existing subsidized housing programs – and the regulations that determine utility allowances – create dis-incentives to

greater energy efficiency. We begin by developing a theoretical framework for why regulations governing subsidy programs affect investment and consumption incentives. We then combine several unique datasets to analyze actual energy use data for all large (greater than 50,000 sq. ft.) subsidized and market-rate multifamily properties in New York City for the first time. This unique dataset, consisting of more than 4,000 properties, is then used to model the variation in energy consumption across the multifamily rental housing stock and test whether regulations result in higher energy consumption in subsidized properties than in comparable non-subsidized properties. Using several multivariate regression models, we find that subsidized properties are associated with higher utility consumption than market-rate properties and, of the subsidized housing programs, Public Housing tends to consume the most energy. The findings in this paper suggest that despite the potential for retrofitting multifamily properties, there are often regulatory factors that constrain investment and consumption decisions in the case of subsidized properties.

2. Background and Literature Review

There is relatively little understanding of how regulations in the multifamily housing sector affect energy consumption levels or how consumption levels in subsidized properties compare to those that are market rate. One study finds that utility costs for the U.S. Department of Housing and Urban Development (HUD) increased by 35 percent between 2004 and 2010, from US\$6.3 to US\$8.5 billion (White, 2012). However, that report is limited to HUD properties and does not analyze whether these increases are due to program structure, tenant or building characteristics, or escalations in energy prices. There is only one study that compares utility costs across subsidized and unsubsidized properties; it finds that, on the whole, subsidized properties have higher costs than similar market rate properties, but these difference largely disappear when controlling for household characteristics (Dastrup et al. 2012). The study uses American Housing Survey data, which has limited information on the type of rental subsidy and therefore conflates all subsidized units into one larger “subsidized” category. In addition, the study is a national analysis and has low statistical significance when all of the building, household, and spatial controls are included. The lack of differentiation between subsidy programs, combined with a limited sample size reduce the scope and significance of the findings.

There are numerous studies that model or analyze the determinants of energy use in residential buildings. Most tend to focus on single-family structures and use simulations or physical models to estimate consumption patterns when actual use data are unavailable. Swan and Ugursal (2009) present an overview of modeling approaches for residential building energy use, focusing on macro-scale and

building-scale models. In general, the review highlights the coarse and relatively low resolution analysis of residential building energy use in the literature, either using historical data at a neighborhood or city scale, or using prototypical buildings to estimate aggregate consumption. Several studies use statistical methods and actual building consumption data to understand the factors that impact building-level consumption and predict energy use across residential buildings. Yohanis et al. (2008) conduct a study using a small sample of just 27 dwellings to understand the effects of unit size and occupant density on energy use. Kontokosta (2012) examines residential energy use using robust statistical methods applied to actual energy use data for more than 6,000 residential buildings in New York City. The author finds statistically significant coefficients for several building bulk and size variables, building age, geospatial characteristics, and building amenities, such as laundry facilities. In a study of approximately 4,000 residential buildings in Ireland, McLoughlin et al. (2012) find that the size of the dwelling and socioeconomic characteristics of the household impact energy consumption.

In our comparison of subsidized and market-rate residential buildings, we explore several factors that may influence differences in energy consumption patterns. It can be expected that building quality and systems in subsidized housing are inferior, on average, to market-rate properties, and that these deficiencies will negatively impact energy efficiency. Building quality is affected by both building systems (age and efficiency of boiler, for instance) and construction materials, such as the R-value of wall assemblies and glazing efficiency (Perez-Lombard, Ortiz, and Pout 2008). We anticipate that the variation in building quality will be a function of the subsidy program category for a particular building. Specifically, we expect that housing quality should be on par with market-rate housing in some programs where the buildings are newer and the program leverages private capital, whereas older subsidy programs may exhibit lower levels of building quality due to development budget constraints and inferior or deferred maintenance, among other factors.

Occupant behavior has been shown to have a significant impact on energy consumption in residential buildings (Lutzenhiser 1993; Ouyang and Hokao 2009). Studies have found that factors such as occupant density (Kontokosta 2015); occupant behavior (McMakin et al. 2002; Santin et al. 2009), and socioeconomic and cultural differences (Kontokosta and Jain 2015) affect consumption behavior. Accounting for occupant characteristics has been shown to be an important, although challenging, component of understanding relative energy efficiency. With the exceptions of the citations above, most studies of the impact of occupants on consumption behavior are derived from models, simulations, or surveys rather than actual energy use data (Langevin, Gurian, and Wen 2013). While these methods are

useful for cross-validation and estimating potential impacts, the empirical analysis of actual use data provides an opportunity for new insights into the effects of these factors on building energy efficiency.

3. Theoretical Framework

We motivate our empirical analysis by formalizing a theoretical framework for the drivers of energy use in subsidized housing, shown in the function below. This allows us to identify the drivers of energy use and where they differ between subsidized and similar market-rate properties. For our consumption model, energy use in subsidized housing is given by:

$$\widehat{y}_{it} = f(H, O, M, S, W, P) \quad (1)$$

Where y is the expected annual energy use intensity (EUI, in kbtu per square meter) of building i at time t , H is the quality of housing in building i at time t , O is the occupant characteristics of building i at time t , M is the metering arrangement of building i at time t , S is the subsidized housing program that building i is a part of in year t , W is the weather at time t , and P is the price of energy for building i at time t . The price of energy is a function of the types of energy consumed (e.g. natural gas, fuel oil, electricity, etc.) and can vary as price expectations fluctuate over time (Amstalden et al. 2007). By controlling for these factors in our empirical model, we can isolate the impact of the programs on relative measures of energy efficiency, operationalized here as the annual, weather-normalized EUI of the building, accounting for all energy consumed in the building divided by its total gross square meter.

In all rental properties, owners have control over housing quality, H , and metering configuration, M . Housing quality is a function of both the initial design and installed systems of the building, and how the building has been maintained over time to ensure building systems work to their maximum efficiency. The metering configuration refers to whether the building is master-metered and the owner pays utilities for the building, or if units have individual meters and tenants are responsible for paying for their own utilities. When tenants are not directly metered, and utility costs are included in rent, an owner has an incentive to increase the energy efficiency of the building by improving its quality (H). A building's net operating income is a function of total revenue and is given by gross rental revenue less operating costs ($R_t - C_t = NOI_t$), which consist of several components, including utilities. Improved energy efficiency will reduce the building's operating costs (C) and thus increase net operating income (NOI), holding gross revenue (R) constant. The decision to invest capital in energy efficiency upgrades will be determined by the net present value of future cash flow (expected energy cost savings) less the first, or up-front, capital cost of installing energy efficiency improvements.

Thus, if the expected future increase in savings exceeds the initial capital cost, then a building owner should be willing to invest in energy efficiency improvements because it will increase their NOI (holding R constant). This assumes, however, that tenants will not alter their energy use behavior in such a way as to consume more energy and offset the energy savings associated with energy efficiency investments. This behavior has been described as the “rebound effect” (Gillingham, Newell, and Palmer 2009; Greening, Greene, and Difiglio 2000; Madlener and Alcott 2009). Given this uncertainty, the discount rate, r , in the owner’s decision analysis will be higher than alternative investments to account for the anticipated risk of the realized energy savings from the technologies over time and the likelihood in a shift in the tenants’ energy consumption behavior.

In the case where the building is sub-metered, meaning that tenant (apartment) energy consumption is directly measured and the tenant pays for some or all of their utilities, an owner only has an interest in making an energy efficiency investment if: 1) it allows them to increase rents and the value of that increase over time exceeds the cost of investment or 2) the inefficiency of the building decreases the asking rent such that the value of that discount is greater than the cost of investment.

An owner’s investment calculation is different for subsidized versus unsubsidized rental housing, and varies based on the subsidy program (S). First, in the Public Housing program where quasi-government entities called Public Housing Authorities (PHAs) act as owners, rent levels are approved by HUD, thus placing a limit on revenue and rental rate growth. In addition, all of the operating costs for a property in the Public Housing program are reimbursed through a HUD operating subsidy that is based on the average operating costs over the prior three years. Historically, if a PHA’s costs are lower than the budgeted amount, the PHA keeps 75 percent of cost savings in that year, but the operating budget is then decreased by that 25 percent and then further decreased by virtue of the lower cost being calculated going forward on a three-year moving average. This means that a PHAs investment return from any energy efficient investment also needs to be discounted by the fact that HUD keeps a portion of those savings and reduces its operating subsidy. On the other end, if costs increase, the PHAs’ budget is increased through a similar formula, which consequently does not allow the PHA to recoup all of its losses in that year.

The project-based Section 8 program finances private owners of subsidized housing. Through this program HUD also approves rents, but the rent levels are capped by local market rents. In addition, HUD reimburses the owner directly for operating costs through a series of cost adjustment mechanisms, and owners often only receive approval for rent increases to cover operating cost increases. In essence,

HUD covers some or all of the cost of inefficient systems through cost adjustments, and in some cases, incentivizes higher costs through its rent calculation system. As a result, an owner in this program would only make energy efficient investments if the value of the cost savings from the investment exceeded the value of future rent increases that would have been justified by higher costs.

The Low-Income Housing Tax Credit (LIHTC) regulations offer the strongest incentives for efficient utility investments of all of the subsidy programs. The simplified structure of this program is that property developers apply for tax credits. If awarded these credits, the developers then sell the credits to raise capital that is used to lower construction and permanent loan levels. Reduced debt service payments allow developers to charge lower rents that are affordable to low-income households set at a level defined by the government. Through this program, the total revenue is fixed. If the owner pays for utilities, they must pay all utility costs from the property's rental income and cannot adjust rents higher in response to higher costs. As a result, owners of these properties have an interest in minimizing costs (C) to increase NOI or to install submeters to bill tenants directly for energy costs.

In the case of the LIHTC program, tenants have a similar utility allowance, but owners have an incentive to minimize the allowance amount because there is no ongoing operating subsidy to the owner that increases if the utility allowance increases. A higher utility allowance lowers the owners' net operating income and provides an incentive for owners to make property investments in LIHTC properties. With submetering, tenants have an incentive to use energy more efficiently because they keep any savings accrued from consuming less than their utility allowance amount. One of the challenges of a utility allowance is that it gives households the option to choose between spending money on energy consumption in their unit or consumption on all other goods. As a result, if the utility allowance is not correctly sized, a tenant's decisions will become constrained and they will be forced to make tradeoffs between a minimal level of thermal comfort and other goods. Theoretically, public entities develop utility allowances based on the efficiency of the building, and a smaller allowance is a product of a lower level of cost associated with heating and cooling a unit. However, if these utility allowances are not sized correctly and adjusted based on the characteristics of that particular building and household, the utility allowance could be too low and a budget constrained low-income households could be forced to sacrifice almost all heating and cooling in order to pay for their other non-housing needs.

For submetered subsidized buildings across all programs, where tenants pay utility costs directly, the building owner has little incentive to invest in energy efficiency improvements that only

benefit the individual units because (1) the tenant disproportionately benefits through lower energy expenditures and (2) the owner is unable to increase rent to reflect the lower operating costs.

Next, we look at this structure from the perspective of a tenant's location decision. In a two-good world where a tenant is making a decision between rent and utilities, the tenant will attempt to maximize their welfare by adjusting their energy use behavior or selecting a more energy efficient unit. A tenant has a lower marginal cost of utility consumption in a more efficient unit. This means that a household in a more efficient unit will spend less than a similar household in a less efficient unit for the same level of utility consumption. As a result, if a household knows the level of costs savings, given some degree of certainty, they should be willing to pay more for the more efficient unit, up to the limit of the difference in the marginal cost of utilities between the two units.

There are several factors that alter this calculation in subsidized housing (Bird and Hernandez 2012). First, the demand for subsidized housing often exceeds the supply, which means tenants cannot shop for a more efficient unit.¹ This reality reduces the pressure on owners to make energy efficient investments to attract tenants. In addition, in the case of public housing and project-based Section 8, when tenants pay for their utilities, a portion of the rent payment is reduced by a utility allowance and HUD increases its portion of the rent payment by that allowance amount. These utility allowances are often set at the building level and are calculated based on the average consumption levels for tenants in that building in the previous year and are adjusted based on the number of bedrooms in a unit. As a result, if tenants increase their consumption, their allowance subsequently increases and rent payments decrease in the following period to ensure they spend no more than 30 percent of their gross income on rent and utilities. HUD does not provide a benchmark for determining what a reasonable utility allowance is, and there is no feedback mechanism for what one's utility consumption "should" be.² In aggregate, this utility allowance adjustment system shields households from the repercussions of overconsumption, and in doing so reduces their desire to reduce energy consumption or shop for a more efficient unit (if they could). The owner receives the same overall amount for rent plus utilities, regardless of the utility allowance amount, which also makes them indifferent about making energy

¹ In 2016 there were almost 260,000 households on the waiting list for Public Housing in New York City and nearly 150,000 households on the waiting list for Section 8 Vouchers
<https://www1.nyc.gov/assets/nycha/downloads/pdf/factsheet.pdf>

² PHAs must set the allowance to "approximate a reasonable consumption of utilities by an energy-conservative household of modest circumstances consistent with the requirements of a safe, sanitary, and healthful living environment." 24 C.F.R. § 965.505(a)

efficient investments. Combined, these factors mean that in the Public Housing and Project-based Section 8 programs there is no pricing incentive for the landlord to increase the efficiency of the unit, or for tenants to reduce consumption levels.

Finally, an important factor to note is that weather (W) and pricing (P) are out of the control of both tenants and owners, although pricing is influenced by the type of fuel used for heating and hot water. Household characteristics (O) could be influenced by the subsidized housing programs because each program targets households within a certain income band, and variations in consumption behavior can be tied to household characteristics.

4. Data

One of the challenges facing the study of utility consumption in subsidized properties is the availability of data on which properties are subsidized, the tenants who live in these properties, and actual utility consumption levels. In this paper, we combine several unique databases that allow us to analyze utility costs across subsidy programs, as compared to market properties, for the first time. First, we use Local Law 84 (LL84) data, which provides actual building-level energy consumption data for all multifamily properties in New York City larger than 4,500 square meters, categorized by total consumption and consumption by energy type (City of New York 2016; Kontokosta 2013, 2015). We combine these data with detailed information on the characteristics of all subsidized properties in New York City, including every subsidy layer on a property, from the Subsidized Housing Information Project (SHIP) maintained by the NYU Furman Center for Real Estate and Urban Policy. Finally, we combine both of these datasets with comprehensive building characteristics data, including building size, building age, and whether and when a building was last altered, among others features, from the New York City Department of City Planning's Primary Land Use Tax Output (PLUTO) database, and neighborhood demographic and socioeconomic data from the U.S. Census American Community Survey. Together, this integrated dataset allows us to develop a detailed picture of energy consumption and building characteristics for all large multifamily properties in New York City, and analyze how consumption varies between subsidized and unsubsidized properties and across subsidy programs.

Our energy data used here represent actual energy consumption, by energy type and source, for calendar year 2013 across 15,000 properties, representing 261 million square meters of space in total. Of these, the LL84 data were cleaned to account for data entry errors, duplicates, and outliers (Kontokosta 2012; Kontokosta, Bonczak, and Duer-Balkind 2016). Multi-stage data cleaning represents a

critical component of building energy analytics and the ability to extract reliable insight from self-reported energy data. Variable headers and other entries are cleaned of atypical characters and formatting inconsistencies; omitted or missing values are dropped or imputed, as appropriate; and outliers are identified and removed prior to our analysis. We account for outliers in the energy dataset by first conducting a log-transform of the data based on reported EUI, as its unaltered distribution is asymmetrical and has the right-skew characteristic of a logarithmic-normal distribution. Taking the natural logarithm of EUI normalizes the distribution and allows for the use of the standard deviation as a threshold to detect outliers, and we consider values above or below two standard deviations from the mean as outliers in this work.

The SHIP database is a publicly-accessible database that was developed by the NYU Furman Center for Real Estate and Urban Policy to track subsidized properties in New York City. The SHIP database catalogues the nearly 235,000 units of privately owned, publicly subsidized affordable rental properties built in New York City. This database combines more than 50 government databases and account for all public subsidy layers on every rental property in New York City (Reina and Williams, 2012). These data allow us to develop a more robust understanding of what regulatory frameworks are governing the utility costs in a building, and whether there are regulations from multiple subsidy programs influencing decisions on utility consumption.

We merge the LL84 and SHIP datasets using a spatial join process in ArcGIS coupled with fuzzy logic matching on Borough-Block-Lot (BBL) number and text address. In total, we identify 783 properties that have a subsidy through the Public Housing, LIHTC, or HUD's Project-based Section 8 programs for which energy data were reported. We use the SHIP dataset to determine all of the subsidy layers on each property and find that 259 properties had more than one form of subsidy. For the analysis, we recode this subsidy layer descriptor to a binary flag for whether a property received a subsidy from any program, and then a flag for each subsidy that it received.

As seen in Table 1, there is observed variation in the characteristics of market versus subsidized properties, and across individual subsidy programs. The first thing to note is that subsidized properties comprise almost 20 percent of the sample. On the whole subsidized properties tend to have a slightly higher share of residential units and larger unit sizes, therefore controlling for variation along these dimension is important. Approximately 76 percent of subsidized units have gas as the primary fuel type, whereas market rate properties tend to have gas or oil, which means we want to determine what share of the variation in energy use is attributable to the difference in primary source of energy. As previously

stated, metering arrangements likely affect utility consumption. In our data, we find that over 90 percent of properties with no subsidy are submetered, 84 percent of LIHTC properties are submetered, 77 percent of Section 8 properties are submetered, and only 36 percent of Public Housing properties are submetered.

Table 1: Summary Statistics

	Subsidized		LIHTC		Public Housing		Section 8		Market	
	(783 properties)		(254 properties)		(150 properties)		(407 properties)		(3,632 properties)	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Source EUI (kbtu per square meter)	13.03	4.89	13.16	3.80	13.34	4.75	12.84	5.49	11.32	4.24
Site EUI (kbtu per square meter)	7.86	2.93	7.66	2.17	8.40	3.64	7.80	3.00	7.43	2.91
GHG intensity (mtCO ₂ e/1,000 square meter)	0.53	0.21	0.51	0.15	0.54	0.21	0.56	0.26	0.52	0.22
Percent residential	98.80	5.76	97.53	9.37	99.97	0.40	99.11	3.00	97.44	12.27
Square meter per unit	100.33	69.68	104.98	98.47	102.19	58.53	95.69	45.52	98.47	34.37
Laundry hookup in each unit (1 if yes)	0.06	0.23	0.11	0.31	0.00	0.00	0.04	0.19	0.19	0.39
Dishwasher in unit (1 if yes)	0.09	0.29	0.20	0.40	0.00	0.00	0.04	0.21	0.14	0.34
Building is on a corner lot (1 if yes)	0.51	0.50	0.48	0.50	0.51	0.50	0.55	0.50	0.50	0.50
Number of stories	10.06	8.38	11.45	10.54	9.57	6.27	9.38	7.18	8.28	5.98
Building 20-39 years old (1 if yes)	0.26	0.44	0.14	0.35	0.18	0.39	0.38	0.49	0.03	0.17
Building 40-59 years old (1 if yes)	0.19	0.39	0.02	0.14	0.43	0.50	0.20	0.40	0.19	0.39
Building 60-79 years old (1 if yes)	0.03	0.18	0.00	0.06	0.15	0.35	0.01	0.09	0.22	0.41
Building 80-99 years old (1 if yes)	0.22	0.41	0.20	0.40	0.19	0.39	0.24	0.43	0.44	0.50
Building 100+ year old (1 if yes)	0.06	0.24	0.06	0.23	0.05	0.21	0.06	0.24	0.06	0.24
Primary fuel gas (1 if yes)	0.76	0.43	0.84	0.36	0.77	0.42	0.71	0.46	0.45	0.50
Primary fuel oil (1 if yes)	0.09	0.29	0.06	0.24	0.01	0.08	0.14	0.35	0.43	0.50
Primary fuel other (1 if yes)	0.03	0.16	0.03	0.16	0.05	0.23	0.02	0.15	0.01	0.10
Number of bedrooms per unit	1.60	1.33	1.67	1.78	1.83	1.23	1.46	0.93	1.29	0.90
Unemployment rate of tract	13.85	6.29	13.36	6.10	15.94	6.43	13.17	6.19	10.74	5.25
Submetered	0.68	0.47	0.84	0.37	0.36	0.48	0.77	0.42	0.91	0.29

We use two metrics for energy consumption: 1) site energy use, which is the energy consumed by the building as given by meter readings and oil deliveries; and 2) source energy use, which accounts for the energy consumed by the building, as well as the energy used and lost in the generation and transmission of the energy to the building (Kontokosta 2015; U.S EPA 2013). Source energy is considered a more equitable measure of building performance for comparison since it accounts for different energy types, based on standard U.S. Environmental Protection Agency (EPA) conversion factors. Source energy use is typically used in the analysis of energy benchmarking data when the primary consideration is the carbon emissions associated with building energy use (City of New York 2014a). Market-rate properties have the lowest mean site and source energy use per square meter (referred to as EUI) and Public Housing has the highest in both categories (see Table 1). This purely descriptive analysis provides some preliminary support for our hypothesis that subsidized properties consume more energy than market rate properties, and that within the subsidy programs, Public Housing consumes the most. Below, we develop a series of models to test for statistically significant differences across portfolios and control for property and household characteristics that impact energy consumption in order to understand whether higher consumption is due to program structure or other factors.

One initial challenge is that data on the demographic and socioeconomic characteristics of the tenants living in these properties is not available. To overcome this limitation, we use develop two proxies to estimate these factors. First, we include the average number of bedrooms per unit as a proxy for the number of people in a unit given the relationship between household size and number of bedrooms. The descriptive statistics in Table 1 show that subsidized properties tend to have higher bedroom counts than market-rate properties, which means there are likely more people per unit consuming energy. Second, we include the tract³-level unemployment rate to account for local economic conditions. It serves as a proxy for the economic strength of a particular area, and thus likely representative of the tract's residents, and as signal that a higher rate could mean that households are home for a larger share of the day and therefore likely to consume more utilities. The descriptive statistics also show that subsidized housing is located in census tracts with higher unemployment rates.

³ Tracts refers to a census tract, which a unit of geography created by the U.S. Census Bureau that is meant to be small and consistent and allow for data analysis over time. In New York City, the study area of this paper, there are 2,168 census tracts, with each tract covering a land area of roughly 36.4 hectares that usually covers a population of 3,000 and 4,000 people.

5. Methodology

Using a multivariate regression approach with robust standard errors, we develop a base model to understand the variation in energy consumption between subsidized and unsubsidized properties, and across different subsidy programs, and then re-specify the model in several ways. The base model is as follows:

$$y = \alpha + \beta_1\chi + \beta_2\lambda + \beta_3\theta + \varepsilon \quad (2)$$

The outcome y is the natural log of the site EUI for a particular building. We use a natural log transform of the dependent variable to account for the observed right-skewed distribution of EUI in our sample. The intercept is α . We create a series of binaries, χ , for the building's subsidized portfolio. In the first model, we created a binary variable where 1 signifies that the property receives some form of rental subsidy and 0 indicates that property has no subsidy, otherwise known as being "market rate." λ is a vector of building characteristics that could affect consumption levels, including the percent residential floor area in the building, the log of the gross floor area of the building and square meter per unit, whether there is laundry in the unit, whether there is a dishwasher in the unit, whether the building is on a corner lot, the number of stories in the building, the decade the building was constructed, and the primary energy source (defined as the energy source accounting for more than 50 percent of total site energy consumption). θ is a vector of variables that we use to proxy for the household's characteristics that could affect consumption levels, which includes the number of bedrooms per unit, and the log of the unemployment rate of the census tract. Finally, ε is the error term. We then re-specify this model to include whether the building is submetered. Finally, we run both of these models with the log of the source EUI as the dependent variable, instead of site EUI, to account for differences in energy sources consumed at the building.

Next, we use these same four model specifications, but transform the *Portfolio* variable into a series of binary variables by subsidy program – Public Housing, Project-based section 8, and LIHTC – to determine whether a property is in that particular program or not. This specification allows us to look at the variation between market-rate properties and specific subsidy programs. In addition, this approach allows us to account for the fact that some properties receive subsidies from multiple programs. For example, if a property receives funding from both the Project-based Section 8 and LIHTC programs, that property has a 1 in the Project-based Section 8 variable, a 1 in the LIHTC variable, and a 0

in the Public Housing Variable. A property that is market-rate, and receives no federal rental subsidy, has a 0 in all three program binary variables.

6. Results and Discussion

The results from the first model are shown in Table 2. This model includes the binary “Subsidy” variable for whether the property received any form of federal rental subsidy to discern if there is a difference between subsidized and market rate properties. Our outcome variable is the log transformation of building EUI. Therefore, we interpret the exponentiated value of the coefficient as the percentage change in EUI for a unit change of the respective independent variable. As column one and three show, after controlling for building and household characteristics, subsidized properties are found to have statistically significant higher EUIs than market-rate buildings, a finding that holds for both site and source EUI. Specifically, subsidized properties have a 10 percent higher site EUI than similar market-rate properties, and a 12 percent higher source EUI.

As discussed previously, we expect that the metering arrangement of the property will affect energy consumption. We estimate the model with a binary “Submetered” variable, equal to 1 if the property is sub-metered, and 0 otherwise. As seen in columns 2 and 4 in Table 2, properties that are submetered have a 20 percent lower site and source EUI, controlling for other factors. When accounting for the metering configuration of the building, we no longer find a statistically significant difference in EUI between subsidized and market rate properties. This finding is particularly important, as the positive effect of submetering holds regardless of the regulatory context of the building. However, we expect that there is still variation between market-rate and subsidized properties within each metering category, which is an important dimension we explore later in the analysis.

Table 2: Log energy use of subsidized properties with market-rate properties as the base group

	Site EUI		Site EUI		Source EUI		Source EUI	
Subsidized	0.095	***	0.092		0.110	***	0.072	
Percent residential	0.142	***	-1.262	**	0.010	**	-1.054	*
Square meter in building	-0.069	***	-0.138	***	-0.066	***	-0.134	***
Square meter per unit	-0.188	***	-0.131	***	-0.186	***	-0.124	***
Laundry hookup in each unit	0.005		0.016		0.006		0.070	
Dishwasher in unit	0.053	**	0.107		0.081	***	0.178	**
Building is on a corner lot	0.012		0.003		0.022	*	0.016	
Number of stories	0.013	***	0.011	***	0.015	***	0.013	***

Building 20-39 years old	0.090 ***	0.118	0.026	0.054
Building 40-59 years old	0.176 ***	0.186 ***	0.086 ***	0.117
Building 60-79 years old	0.066 **	-0.050	-0.060 **	-0.215 *
Building 80-99 years old	0.082 ***	0.131 **	-0.022	0.042
Building 100+ year old	0.107 ***	0.213 **	0.004	0.093
Primary fuel gas	1.020 ***	0.855 ***	0.377 ***	0.259 ***
Primary fuel oil	1.086 ***	0.891 ***	0.410 ***	0.273 ***
Primary fuel other	0.849 ***	0.668 ***	0.327 ***	0.114
Number of bedrooms per unit	0.047 ***	0.059 **	0.047 ***	0.045 *
Unemployment rate of tract	0.048 ***	0.013	0.044 ***	0.020
Submetered		-0.223 ***		-0.227 ***
Observations	4,372	620	4,372	620
R²	0.416	0.354	0.178	0.167
*** p<0.01, ** p<0.05, * p<0.1				

As previously discussed, all of the models control for building characteristics and include proxies for tenant characteristics. We find that older buildings tend to consume more energy than newer buildings, which is likely due to increased building standards and improved building technology over time. For example, properties built 100 or more years ago consume approximately 11 percent more energy per square meter than buildings constructed in the last 20 years, holding all else equal. In addition, taller buildings with more stories tend to consume more energy at the rate of approximately 1.3 percent per additional story. We use the number of bedrooms in a unit as a proxy for household size, and find that EUI increases by 5 percent for every additional bedroom in the unit, controlling for other factors in the model. Interestingly, whether there is a dishwasher in a unit only affects EUI when we do not control for metering arrangement, which suggests that households who pay for their own utilities may be less likely to use their dishwasher, or use it more efficiently. Finally, the size of the building, the mean size of the units, and the primary energy source (i.e. electric, fuel, natural gas) are all found to impact building energy intensity across the model specifications. These findings provide additional empirical evidence for the determinants of energy use in multi-family buildings, and act as controls so we can isolate the relationship between rental subsidy programs and building energy use.

We expect that there is variation in energy use across subsidy housing programs, which means that aggregating all subsidized properties into one category masks potential differential relationships across specific rental subsidy structures. To examine the impact of individual subsidy programs, we re-specify the model to include the binary variables for each subsidy program, and present the results in

Table 3. We find that all subsidized properties are associated with higher EUI than market-rate properties, and that Public Housing has the highest level of consumption of the three subsidized portfolios. Specifically, properties in the Public Housing program have a 15 percent higher site energy use than those not in the program, LIHTC properties have a 7.6 percent higher site energy use, and Section 8 properties have a nine percent higher energy use. Again, these relationships are sensitive to the metering arrangement, as shown in columns 2 and 4, and when we control for that, the subsidy coefficients are no longer found to be significant. Public Housing is still associated with higher site EUI, at the 90 percent confidence level, even when controlling for metering arrangement, which reinforces the expectation that this portfolio contains the least energy-efficient buildings.

Table 3: Log energy use by subsidy program with market-rate properties as the reference group

	Site EUI	Site EUI	Source EUI	Source EU
Public Housing	0.146 ***	0.154 *	0.140 ***	0.121
LIHTC	0.073 **	0.084	0.110 ***	0.083
Section 8	0.087 ***	0.081	0.089 ***	0.053
Percent residential	0.140 ***	-1.296 **	0.010 **	-1.065 *
Square meter in building	-0.074 ***	-0.146 ***	-0.069 ***	-0.142 ***
Square meter per unit	-0.187 ***	-0.126 ***	-0.185 ***	-0.119 ***
Laundry hookup in each unit	0.006	0.035	0.006	0.087
Dishwasher in unit	0.054 **	0.119	0.081 ***	0.186
Building is on a corner lot	0.012	0.006	0.022 *	0.018
Number of stories	0.013 ***	0.012 ***	0.015 ***	0.014 ***
Building 20-39 years old	0.079 **	0.107 *	0.027	0.050
Building 40-59 years old	0.165 ***	0.172 **	0.084 ***	0.111
Building 60-79 years old	0.056 *	-0.083	-0.064 **	-0.239 **
Building 80-99 years old	0.072 ***	0.118 *	-0.024	0.035
Building 100+ year old	0.098 ***	0.206 **	0.002	0.089
Primary fuel gas	1.021 ***	0.846 ***	0.377 ***	0.250 ***
Primary fuel oil	1.088 ***	0.901 ***	0.410 ***	0.282 ***
Primary fuel other	0.841 ***	0.634 ***	0.320 ***	0.081
Number of bedrooms per unit	0.047 ***	0.056 **	0.047 ***	0.042
Unemployment rate of tract	0.047 ***	0.011	0.043 ***	0.018
Submetered		-0.208 ***		-0.213 ***
Observations	4,372	620	4,372	620
R²	0.416	0.357	0.179	0.171
*** p<0.01, ** p<0.05, * p<0.1				

Next, we limit our sample to only subsidized properties to explore variations in energy efficiency across subsidized housing programs. This approach allows us to determine if some subsidy portfolios are performing better than others. We only include the LIHTC and Section 8 variables, where the reference group is Public Housing. As we see in Table 4, LIHTC and Section 8 properties do not perform significantly better than Public Housing properties. Based on the model results, we do not find significant differences in EUI across the specific housing subsidy programs, after controlling for physical and occupancy characteristics

Table 4: Log energy use of subsidy programs with Public Housing as the reference group

	Site EUI	Site EUI	Source EUI	Source EUI
LIHTC	-0.024	0.005	0.001	0.016
Section 8	-0.041	-0.041	-0.049	-0.043
Percent residential	-0.240 *	-1.362 **	-0.225 *	-1.083 *
Square meter in building	-0.110 ***	-0.147 ***	-0.109 ***	-0.145 ***
Square meter per unit	-0.095 ***	-0.126 ***	-0.085 ***	-0.118 **
Laundry hookup in each unit	-0.024	-0.000	0.022	0.051
Dishwasher in unit	0.096	0.127	0.139 **	0.209
Building is on a corner lot	0.005	-0.000	0.026	0.016
Number of stories	0.011 ***	0.010 ***	0.013 ***	0.013
Building 20-39 years old	0.102 **	0.102	0.049	0.039
Building 40-59 years old	0.279 ***	0.142 *	0.216 ***	0.072
Building 60-79 years old	0.011	-0.093	-0.146	-0.255
Building 80-99 years old	0.105 **	0.113 *	0.031	0.024
Building 100+ year old	0.194 ***	0.164 *	0.081	0.045
Primary fuel gas	0.781 ***	0.851 ***	0.186 ***	0.255 ***
Primary fuel oil	0.803 ***	0.911 ***	0.188 ***	0.289 ***
Primary fuel other	0.562 ***	0.689 ***	0.060	0.167
Number of bedrooms per unit	0.031 **	0.057 **	0.023	0.043 *
Unemployment rate of tract	0.010	0.019	0.025	0.039
Submetered		-0.250 ***		-0.251 ***
Observations	781	587	781	587
R²	0.316	0.356	0.138	0.171
*** p<0.01, ** p<0.05, * p<0.1				

One consistent finding across all of our model outputs is that metering arrangements have an impact on energy consumption levels. The incentives in the Public Housing and Section 8 programs often make owners indifferent about metering arrangements because they allow owners to recoup

costs associated with higher consumption levels, which reduces the financial benefits of submetering despite its effect on consumption behavior. To better understand what increases the likelihood of a property being submetered, we use a logistic regression model that controls for building and tenant characteristics to analyze the probability that a property is submetered based on: 1) whether it is subsidized and 2) by the type of subsidy. The results from this model are presented in table 5. We estimate the odds ratio for each coefficient to determine whether a property is sub-metered. Subsidized properties are associated with a 93 percent lower probability of being submetered as compared to market rate properties. When we then disaggregate the *Subsidy* variable by program in column 2 we see that all three subsidy programs have a lower likelihood of being submetered than market-rate properties, and that Public Housing buildings have the lowest probability of being submetered.

Table 5: Odds of a property being submetered

	Submetered (Y/N)	Submetered (Y/N)
Subsidized	-2.662 ***	
Public Housing		-2.713 ***
LIHTC		-1.140 **
Section 8		-1.313 **
Percent residential	2.671	2.184
Square meter in building	-0.814 ***	-0.719 ***
Square meter per unit	-0.065	-0.271
Laundry hookup in each unit	-0.839	-1.219
Dishwasher in unit	1.189	0.835
Building is on a corner lot	0.533 **	0.446
Number of stories	-0.065 ***	-0.069 ***
Building 20-39 years old	-2.170 **	-1.807 *
Building 40-59 years old	-4.824 ***	-4.322 ***
Building 60-79 years old	-4.641 ***	-3.727 ***
Building 80-99 years old	-1.914 *	-1.496
Building 100+ year old	-2.648 **	-2.447 **
Primary fuel gas	1.102 ***	1.396 ***
Primary fuel oil	1.647 ***	1.465 ***
Primary fuel other	1.258	1.863 **
Number of bedrooms per unit	0.251	0.386 *
Unemployment rate of tract	-0.394	-0.282
Observations	620	620
Pseudo R²	0.474	0.491
*** p<0.01, ** p<0.05, * p<0.1		

These results match our theoretical expectations that subsidized housing programs reduce the incentives for owners to submeter their properties. We then explore whether subsidized properties

have similar energy use levels as market-rate properties for buildings with similar metering arrangements. We partition our sample master-metered or submetered properties (Table 6) and focus just on source energy use. We find no statistically significant difference in EUI between market rate and subsidized properties that are master-metered, although the lack of significance could be due to the small sample size. However, we do find that subsidized properties that are submetered, particularly those in the Public Housing program, are associated with higher EUI than market-rate properties with a similar metering arrangement, controlling for all other factors. Interestingly, being in the LIHTC program is also associated with higher consumption levels. These results provide an important layer to our analysis because it suggests that metering arrangement alone is not explaining variation in EUI.

Table 6: Log energy use within each metering configuration

	Master-metered		Submetered	
	Source EUI	Source EUI	Source EUI	Source EUI
Subsidized	0.252		0.118 *	
Public Housing		0.022		0.292 ***
LIHTC		-0.015		0.105 **
Section 8		0.112		0.079
Percent residential	-1.178	-0.909	-0.853	-0.773
Square meter in building	-0.158 ***	-0.148 ***	-0.116 ***	-0.147 ***
Square meter per unit	-0.067	-0.072	-0.187 ***	-0.156 ***
Laundry hookup in each unit	-0.025	-0.064	0.168 *	0.187 **
Dishwasher in unit	0.223	0.179	0.223 ***	0.228 ***
Building is on a corner lot	0.032	0.032	0.016	0.041
Number of stories	0.012 *	0.012 *	0.009 **	0.012 ***
Building 20-39 years old	-0.228	-0.35	0.03	0.006
Building 40-59 years old	-0.453	-0.546	0.321 ***	0.31 ***
Building 60-79 years old	-0.782	-0.854	0.007	-0.07
Building 80-99 years old	-0.438	-0.539	0.07	0.0392
Building 100+ year old	-0.446	-0.52	0.129 **	0.093
Primary fuel gas	0.086	0.095	0.581 ***	0.541 ***
Primary fuel oil	-0.254	-0.285	0.602 ***	0.599 ***
Primary fuel other	0.01	0.134	0.202	0.123
Number of bedrooms per unit	0.048	0.048	0.064 ***	0.045 *
Unemployment rate of tract	0.03	0.038	0.019	0.01
Observations	190	190	430	430

R^2	0.194	0.196	0.271	0.302
*** p<0.01, ** p<0.05, * p<0.1				

Conclusion and Policy Implications

There are several key takeaways from our analysis. First, subsidized properties on the whole tend to consume more energy than market-rate properties, even when controlling for a range of factors that have been found to influence building energy consumption. Specifically, properties in the Public Housing program tend to consume the most energy of the subsidy programs. However, across all models, when we control for the metering arrangement, we find that whether tenants pay for at least some of their utilities is a significant factor in energy use across programs. Not surprisingly, we find that subsidized properties tend to have a lower probability of being submetered, with properties in the Public Housing program most likely configured with whole-building meters. When we focus solely on submetered properties, we find that subsidized properties on the whole, and Public Housing in particular, are associated with higher energy consumption than market-rate properties with similar billing arrangements. Although we find that government subsidy programs tend to create dis-incentives for sub-metering, submetered subsidized housing still under-performs when compared to similar market-rate housing. Combined, this reinforces the theory that regulations governing subsidized housing programs are not resolving the split-incentive problem, which may be contributing to higher utility consumption levels in subsidized properties beyond what might be expected from differences in building and occupant characteristics alone.

Interestingly, properties in the LIHTC program do not perform much better than properties in the other subsidy programs, either in consumption levels or in the likelihood of being submetered. We suspect that this could be due to disconnect between the rules governing the LIHTC program and its implementation. For example, while obtaining these data, we spoke to housing officials in New York City who said it is uncommon for LIHTC owners to receive a utility allowance adjustment that is determined at the building-level, even if they make improvements to their property that warrants such adjustments, due to staffing limitations that prohibit such reviews. If owners cannot adjust their utility allowance level they cannot realize the cost savings of energy efficient investments, which dampens their desire to make such investments. As a result, the regulatory structures for the Public Housing and Section 8 programs could be leading to higher consumption levels, whereas in the LIHTC program the implementation of regulations may be driving higher consumption. Overall, this suggests that while

subsidized housing may seem like low hanging fruit in terms of energy efficiency opportunities, these properties still tend to consume higher amounts of energy due to the design and implementation of the subsidy programs themselves.

There are several changes that can help reduce consumption levels in subsidized housing. Each suggestion is not mutually exclusive because it is important to ensure that both owners and tenants realize the costs and benefits of lower energy consumption levels. First, HUD should mandate that all properties be sub- or check-metered to allow tenants to understand their consumption patterns and support behavior change through information feedback. The growing adoption of “smart” meters is driving down costs and increasing the potential to reduce consumption through usage tracking and benchmarking (Gans, Alberini, and Longo 2013). Smart meters in subsidized rental housing could provide a low-cost method to achieve energy and GHG emissions reduction. Second, HUD should require upgrades for older and less efficient properties, and offer financing programs that make it feasible to make these improvements. Financing through property assessments (such as PACE financing) could be used to enable qualified building owners to pay for energy efficiency upgrades, although limitations in the subsidized rental market exist (Bird and Hernandez 2012). As part of this, developing automated or virtual audit tools to reduce the cost and uncertainty around energy savings opportunities would make it easier for both regulators and owners to determine the energy conservation measures most suitable to the particular property and with the highest return on investment. Machine learning algorithms and rich energy use and energy audit datasets, like those available through disclosure laws, are a promising way to achieve these objectives (Marasco and Kontokosta 2016).

HUD should also revise its calculation of utility allowances on a household-level to one based on an analytics benchmarking model, rather than the current method of estimating allowances based on consumption levels on a building or regional basis. Smart meters would provide a streamlined method to understand real-time and historical consumption at the household level and reduce the uncertainty in measuring and predicting future consumption. Such a change in the allowance calculation would incentivize tenant energy behavior change by allowing tenants to benefit from cost savings realized through energy use reductions in the tenant space (Darby 2012). Finally, HUD should improve access to tenant utility cost and efficiency information prior to lease execution so potential tenants can account for energy efficiency when selecting a unit, and provide a clear feedback mechanism for tenants to contest allowance calculations. As noted in Pazuniak et al. (2015), the majority of these changes can be made to the Project-based Section 8 program through modifications to HUD Guidance, but more

substantial changes to the Public Housing program will likely need to occur through adjusting existing regulations. In the case of the LIHTC program, the issue is not with the regulations, *per se*, but rather with the implementation of the program as currently structured. In this case, the federal government should provide additional support and guidance to local administering agencies to ensure the incentives in the LIHTC program are effectively implemented.

Overall, the theoretical framework and results in this paper show that policymakers and planners interested in reducing energy consumption levels and GHG emissions from the subsidized multifamily housing stock can consider the modification of existing regulations as the low hanging fruit for achieving savings. More broadly these findings highlight the importance of understanding the regulations governing rental housing, and how these incentives can affect tenant and owner behavior when designing interventions aimed at increasing the energy efficiency of the housing stock.

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