NBER WORKING PAPER SERIES

COMMERCIAL BUILDING ELECTRICITY CONSUMPTION DYNAMICS: THE ROLE OF STRUCTURE QUALITY, HUMAN CAPITAL, AND CONTRACT INCENTIVES

Matthew E. Kahn
Nils Kok
John M. Quigley

Working Paper 18781
http://www.nber.org/papers/w18781

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
February 2013

Kahn thanks the UCLA Ziman Center for Real Estate for generous funding. Kok is supported by a VENI grant from the Dutch Science Foundation (NWO). We are grateful to Eric Karlson for help in assembling, interpreting, and verifying the data used in this analysis. We thank Jan Bruecker, Richard Green and participants at seminars at the University of Michigan, Ann Arbor, the University of California, Los Angeles, the 2013 AEA meetings and the Homer Hoyt Institute for useful comments. We mourn the passing of John M. Quigley in May 2012. John was a great scholar, colleague and friend, and he was actively involved in crafting and executing this project. We hope this paper lives up to his expectations. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Commercial Building Electricity Consumption Dynamics: The Role of Structure Quality, Human Capital, and Contract Incentives
Matthew E. Kahn, Nils Kok, and John M. Quigley
NBER Working Paper No. 18781
February 2013
JEL No. H23,H41,Q54,Q55

ABSTRACT

Commercial real estate plays a key role in determining the urban sustainability of a metropolitan area. While the residential sector has been the primary focus of energy policies, commercial buildings are now responsible for most of the durable building stock's total electricity consumption. This paper exploits a unique panel of commercial buildings to investigate the impact of building vintage, contract incentives, and human capital on electricity consumption across commercial structures. We document that electricity consumption and building quality are complements, not substitutes. Technological progress may reduce the energy demand from heating, cooling and ventilation, but the behavioral response of building tenants and the large-scale adoption of appliances more than offset these savings, leading to increases in energy consumption in more recently constructed, more efficient structures.

Matthew E. Kahn
UCLA Institute of the Environment
Department of Economics
Department of Public Policy
Anderson School of Management
UCLA Law School, Box 951496
Los Angeles, CA 90095-1496
and NBER
mkahn@ioe.ucla.edu

Nils Kok
Department of Finance
Maastricht University, Room B1.08
P.O. Box 616
6200 MD Maastricht
The Netherlands
N.Kok@maastrichtuniversity.nl

John M. Quigley †
University of California, Berkeley

I. Introduction

Economic research investigating urban greenhouse gas production has mainly focused on the transportation sector's consumption of gasoline and the residential sector's energy consumption and the power generation sector's energy consumption (Edward L. Glaeser and Matthew E. Kahn, 2010, Koichiro Ito, 2012, Matthew J. Kotchen and Erin T. Mansur, 2012). But in the service economy, most work activity takes place in commercial buildings and a significant amount of shopping activity occurs in the commercial sector's structures. The commercial sector is thus a major user of natural resources, consuming about 19 percent of total U.S. energy use in 2011.[1] Especially the sector's share of overall electricity consumption has been rising over time. As Figure 1A illustrates, the fraction of electricity consumed in residential and commercial buildings in the U.S. has increased from a total of about 52 percent in 1960 (29 percent residential and 23 percent commercial) to about 75 percent in 2010. For comparison, in California the fraction of electricity consumed in buildings has increased from about 65 percent to 81 percent during the same period – the commercial sector currently consumes about a third more than the residential sector in California.

Given that 46 percent of the nation's electricity is generated using coal and 20 percent using natural gas, there is a significant greenhouse gas externality associated with electricity consumption.[2] In the absence of carbon pricing, rising electricity consumption exacerbates the risk of severe climate change.

Despite the importance of the commercial property sector as a major consumer of electricity, we know very little about the environmental performance of its buildings.

[1] See http://www.eia.gov/totalenergy/data/annual/pdf/sec2_6.pdf.
[2] See http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0201f.

Lack of access to good data has limited our knowledge of the core facts – for instance, the most comprehensive source of data, the Department of Energy's Commercial Buildings Energy Consumption Survey (CBECS), was last released in 2003; this nationally representative data set offers cross-sectional information on the energy consumption of just 5,000 buildings. There is a small body of research about commercial building energy consumption, mostly conducted by engineers, exploring either macro trends or analyzing small samples of buildings (see Erick Hirst and Jerry Jackson, 1977, for an early analysis).[3]

In this paper, we exploit access to a unique dataset to study the electricity consumption of a large sample of commercial buildings located in the service area of one California electric utility. By merging the electric utility's data on monthly electricity consumption at the building level with detailed information on building characteristics, occupants and macro-economic trends, we study commercial building electricity consumption dynamics and the environmental performance of different types of commercial buildings at a point in time.

Our data set allows us to track individual buildings' electricity consumption over the past decade. In the first section of the paper, we use the panel data set to test several hypotheses related to how different buildings' respond to changes in outdoor temperature and macro economic shocks. Given that our data set covers the years during the recent great recession, we investigate what types of buildings are most responsive to spikes in the unemployment rate. We also test how the electricity consumption/temperature gradient differs across buildings. For example, we expect that buildings in which tenants

[3] This contrasts a large body of literature on energy consumption in residential dwellings, covering, for example, the determinants of household electricity consumption (Dirk Brounen et al., 2012, Dora L. Costa and Matthew E. Kahn, 2011) and the price-elasticity of residential energy demand (Peter C. Reiss and Matthew W. White, 2005, 2008).

face zero marginal cost pricing will increase consumption more on hot days as compared to buildings with tenants that pay their own bills.

By estimating separately the temperature response curves based on building type, vintage, quality and lease structure, we document evidence that supports the "rebound effect" hypothesis (Lorna Greening et al., 2000). Newer, high-quality buildings in which tenants face a zero marginal cost of energy consume relatively more electricity on hotter days. We interpret this as evidence of how technological progress in building quality is partly offset by the ability to more cheaply achieve ambient comfort – for example with thermostats available on each floor rather than a set temperature that is centrally coordinated.

Using the cross-section of the data, we first explore whether new vintages of commercial buildings are more energy efficient than observationally similar, older vintages of commercial buildings. Given the long lasting durability of the real estate stock, it is important to measure whether new cohorts of buildings are more efficient. It has been documented for vehicles (Matthew E. Kahn and Joel Schwartz, 2008) and for residential homes (Dirk Brounen, Nils Kok and John M. Quigley, 2012, Grant D. Jacobsen and Matthew J. Kotchen, 2013), that more recent vintages consume less energy, but in the case of commercial buildings this has not been studied.

Commercial buildings are differentiated products. Energy efficiency is just one indicator of building quality. Other quality dimensions such as providing good lighting, elevator service, aesthetic appeal and ambient comfort may require using *more* electricity. This claim resembles a key point in Christopher R. Knittel's (2012) study of trends in automobile characteristics. Over time, given that gas prices have been low, he documents that vehicles have become larger and more powerful as carmakers have focused on power and safety as key elements of quality rather than focusing on maximizing vehicle fuel economy. Similar to Knittel's findings for vehicles, we document that, during a time of historically low real commercial electricity prices, newer cohorts of buildings consume more electricity than older cohorts.

The second major set of questions we explore focuses on the role that tenant behavior and tenant incentives play in determining a building's environmental performance. In the case of residential housing, Levinson and Niemann (2004) document that renters whose utilities are bundled into the rent consume more electricity than observationally identical renters who pay their own bills. In a similar spirit, we test whether those commercial buildings featuring renters whose contracts are full service (and thus face a zero marginal cost) consume more electricity.

Owners of such buildings should be aware of the incentive effects and they should have a greater incentive to invest in costly building management to increase energy efficiency. Similar to the Nicholas Bloom et al. (2011) study of industrial energy efficiency, we examine the impact of management quality on energy consumption by addressing the effect of on-site human capital (*i.e.*, the presence of an engineer). We document that buildings where tenants face a zero marginal cost of energy are more likely to have a building engineer on-site. More importantly, those buildings have significantly lower electricity consumption as compared to buildings without an engineer.

The remainder of this paper is organized as follows: Section II describes the empirical framework and the econometric models. Section III discusses the data, which represent a unique combination of building-level electricity consumption with detailed information on the characteristics and occupants of those buildings. Sections IV and V provide the main results, conclusions, and policy implications of the findings.

II. Empirical Framework

Consider the determinants of a commercial building's electricity consumption at a point in time. The building's square footage and architecture will surely influence its current consumption. Once the building is in operation, its electricity consumption will be a function of core building energy consumption (from the requirements to heat, cool and ventilate the building) and consumption from (unobserved) appliances installed and used by the building occupants. For those buildings that attract tenants who tend to use a lot of electricity, such as banks with trading floors and manufacturing companies with energy-intensive equipment, the overall electricity consumption will be higher.

According to national benchmarks for building consumption (*i.e.*, DOE's CBECS data base), heating, cooling, lighting and office equipment account for most of the electricity consumption in buildings, but these estimates are of course heavily dependent on climatic conditions. Figure 2 shows that the heating, ventilation and air-conditioning systems (HVAC) alone account for about 65 percent of energy consumption in commercial buildings. Our sample of commercial buildings from California (the "KKQ Sample") shows larger expenditures on lighting, about 30 percent, and smaller expenditures on HVAC (also about 30 percent) than the nation-wide averages.

People who work in commercial buildings will seek to be comfortable inside regardless of outdoor climatic conditions. For those buildings that have highly efficient air-conditioning systems, it is unclear how hot summer temperatures affect their electricity consumption. The Beckerian "price" of summer temperature comfort is lower in buildings that are newer, as these tend to have more recent, efficient HVAC systems. Facing such an incentive, on hot days, tenants in new buildings may set their thermostat lower than tenants who know that their building has an energy inefficient HVAC system.

This behavioral response is an example of the "rebound effect" such that more energy efficient technology is used more due to the substitution effect (in the case of vehicle fuel economy, see Kurt Van Dender and Kenneth A. Small, 2007, for the case of clothes washers, see Lucas W. Davis, 2008).[4] The size of this rebound effect hinges on the disutility of working in a hot office building, the energy efficiency of the building's HVAC system and the pricing scheme for whether tenants pay for marginal increases in electricity consumption.

Lease contracts identify how the payments for operating expenses (including, but not limited to, energy consumption) are to be allocated between the landlord and the tenants. Lease contracts for commercial buildings commonly take one of three main formats: full service leases, net leases, and modified gross leases. Under a full service lease, the tenant makes one payment that covers both space rent and operating expenses. The individual components are typically not identified. Under a net lease (often referred to as a "triple net" lease), the tenant pays separately for space rent and the tenant's actual or allocated share of the specified operating expenses. Under a modified gross lease, contracts specify a payment for the space rent and require an actual amount to be paid for operating expenses in the first year. For later years, the landlord provides an audit of building expenses, and the tenants pays a prorated share of the realized percentage increase in the building expenses. So, modified gross leases and net leases share the feature that the tenant pays a share of the building's operating expenses, but on modified gross leases the tenant pays a prorated share of the building's total expenses, which are thus are independent of the tenant's actual energy usage. (See Dwight Jaffee et al., 2012,

[4] Another possible hypothesis is that new buildings often do not have windows that open so all cooling and heating comes from the heating and cooling system. Some of the older buildings have windows that open so they can delay using air-conditioning in the early part of summer and stop using air-conditioning earlier at the end of summer.

for a discussion.) We seek to test hypotheses about the role of incentives provided by various contracts, such as specifying a zero marginal cost of consumption, on total electricity consumption.[5]

Achieving efficient use of electricity requires certain human capital and expertise. If experts are paid a market wage, then it is unlikely that smaller commercial buildings will employ human capital, because the expected present discounted value of reduced electricity bills is likely to be low. Employing a building manager is expected to deliver significant electricity consumption reductions. Nicholas Bloom et al., (2011) document using a survey of UK managers that manufacturing plants have a lower energy intensity (energy consumption per dollar of value added) at plants featuring more skilled managers. We conjecture that a similar effect plays out for commercial real estate, where the presence of an on-site building manager or engineer might have an effect on how efficiently a property is operated and maintained – especially in those buildings where tenants face a zero marginal cost of energy consumption.

Finally, by calendar year and month, macro conditions will also affect consumption, for example through climate patterns and economic conditions. During a recession, a commercial building's occupancy rate will decline and this will cause a reduction in electricity consumption.

[5] We assume lease contracting is exogenous and thus uncorrelated with unobserved determinants of electricity consumption. Data access has limited research examining how contractual form affects economic performance. Eric D. Gould et al., (2005) use a unique dataset of mall tenant contracts and show that rental contracts are written to: efficiently price the net externality of each store, and align the incentives to induce optimal effort by the developer and each mall store according to the externality of each store's effort. Arik Levinson and Scott Niemann (2004) document for a sample of residential homes that market rents for full service, utility-included apartments are higher than for otherwise similar metered apartments. This difference is smaller than the cost of the energy used, which indicates that landlords value the contractual arrangement more than the potential additional energy consumption. There is no evidence on contract form related to tenant energy consumption in the commercial building sector and we assume that profit-maximizing landlords only offer utility-included leases if the expected energy consumption of tenants is lower than the marginal revenue of such a contract.

To explain the longitudinal and cross-sectional variation in commercial building energy consumption, we estimate the following models:

(1) $$\ln(E_{it}) = \beta TEMP_t + \gamma OCC_{it} + \delta EMPL_i + \alpha_i + \beta_y + \tau_m + \varepsilon_{it}$$

(2) $$\ln(E_i) = \beta X_i + \gamma d_i + \varepsilon_i$$

In equation (1) we estimate a time-series model with building-fixed effects, in which the dependent variable is the logarithm of the average daily electricity consumption per square foot in month *t* (in kilowatt hours) for building *i*. $TEMP_t$ is a vector of temperature dummies capturing the non-linear relation between outside temperature and building energy consumption, OCC_{it} is the occupancy rate in building *i* in month *t*, and $EMPL_i$ is the local unemployment rate (reflecting the business cycle). α_i is a variable capturing building-fixed effects, controlling for the time-invariant characteristics of each property *i*. β_y are year-fixed effects and τ_m are month-fixed effects, both controlling for unobservable shocks to electricity consumption common to each building *i*. ε_{it} is again an error term, assumed i.i.d.

In equation (2), we estimate a cross-sectional model, with X_i as a vector of the structural characteristics of building *i,* including building size, vintage, and quality. To control for locational variation in energy consumption, we also include a variable measuring the distance *d* of building *i* to the center of the commercial building district (CBD). ε_i is an error term, assumed i.i.d.

While this paper investigates electricity consumption, we do not attempt to estimate a demand curve for commercial electricity. Our data comes from an electric utility whose pricing tiers feature little variation or increases from peak to off-peak. To further control for average price variation, we include month fixed effects.[6]

In studying each of these factors, we use our unique data set that we describe below. Despite the large number of variables that we can access, we recognize that there will be unobserved determinants of building electricity consumption. In estimating equation (1) using a fixed-effects regression, and estimating equation (2) using OLS, we are assuming that the error term is not correlated with the explanatory variables. We will return to this point below after the discussion of the data.

III. Data

Through a research partnership with a California electric utility, we access monthly electricity consumption for more than 50,000 commercial accounts within the service area. We focus on the subset of buildings that we can match to the buildings identified in the archives maintained by the CoStar Group. The CoStar service and the data files maintained by CoStar are advertised as "the most complete source of commercial real estate information in the U.S,"[7] and has been used extensively in academic studies on the commercial property sector (see for example Piet M.A. Eichholtz et al., 2010). Spanning the years 2000 to 2010, our match yielded 38,906 accounts in 3,521 buildings for which information on occupants, lease contracts and building characteristics could be identified in CoStar. Our sample represents the population of

[6] Ito (2012) documents that residential electricity consumers are more responsive to average prices than marginal prices, estimating a price elasticity of roughly -0.05.

[7] The CoStar Group maintains an extensive micro database of approximately 2.4 million U.S. commercial properties, their locations, and hedonic characteristics, as well as the current tenancy and rental terms for the buildings. Of these 2.4 million commercial buildings, approximately 17 percent are offices, 22 percent are industrial properties, 34 percent is retail, 11 percent is land, and 12 percent is multifamily. A separate file is maintained of the recent sales of commercial buildings.

transacted buildings (in either a lease or a sale) over the years 2000 to 2010.[8] The building types in the sample include "Office," "Flex," "Industrial," and "Retail" properties. In this study, we do not consider multi-family residential buildings.

Information on monthly electricity use is available on both consumption and expenditures, including information on the start date of each billing cycle. To account for variation in billing cycles, we transform electricity consumption and expenditures into daily data, by dividing the billing cycle totals by the number of days in the cycle. If data are available for multiple accounts within a single building (there are about three accounts per building, on average), we then aggregate the daily energy consumption at the building level.

Data on local daily weather conditions is collected from the National Oceanic and Atmospheric Administration's (NOAA) Climatic Data Center. We calculate the average maximum daily temperature during the billing cycle for each building, averaging across accounts if there are multiple accounts within a single building.[9]

Information on building occupants is gathered from the CoStar Tenant module. For each building in the sample, we collect data on the floor space occupied and the identity of the tenants. The industry of each tenant is classified by a four-digit SIC code,

[8] One reader noted that this might lead to selection bias, as the thermal quality of owner-occupied properties may differ from "investment" properties. But the direction of the bias is not obvious: owner-occupiers may have a longer holding period, allowing for investments in building retrofits and more energy-efficient equipment, without the requirement of short "payback periods," which is often quoted as a barrier to energy-efficiency upgrades. However, one could also argue that professional property investors are more rational agents when it comes to trading off large upfront investments with savings realized over a longer time period. And well-capitalized institutional property investors may suffer less from liquidity constraints as compared to smaller, private real estate investors and owner-occupiers.

[9] Presumably, commercial properties are occupied mostly throughout the day, so it is the maximum daily temperature that matters for energy consumption, not the average daily temperature. A robustness check using the average daily temperature does not yield significantly different results (results available from the authors upon request).

and we aggregate the fraction of floor space occupied into thirteen groups.[10] Our interest is primarily in the behavior of government tenants and the efficiency of the buildings of this specific tenant group.

Table I presents a description of the four types of commercial buildings in our sample (for 2009). Average energy usage varies from about 11,000 kWh per month for industrial buildings to three times that for office buildings. Our sample includes some centrally located, high-rise, and high quality ("Class A") properties, but on average the distance to the city center is some twelve kilometers; the majority of properties are low-rise (about two stories) and fall into quality categories "B" and "C."[11]

The vintage of properties in the sample is fairly young (some 27 years, on average) as compared to the residential building stock – Dora L. Costa and Matthew E. Kahn (2011) report for the same geography that about fifty percent of the residential dwellings were constructed before 1970.

IV. Results

A. Electricity Consumption Dynamics

In this section, we exploit our full building panel dataset from 2000 to 2010 to study the role of dynamic factors in determining a building's electricity consumption, *i.e.*, how a building's electricity consumption varies as a function of climatic conditions (the average daily maximum outdoor temperature during the billing cycle) and the business

[10] The thirteen groups are defined in line with the U.S. Department of Labor SIC guide, and include: Agriculture & Mining; Construction; Manufacturing; Transportation; Communication; Utilities; Distribution; Retail; Financial; Services; Non-Profits; Professional Services; and Government.

[11] The Building Owners and Managers Association (BOMA) groups commercial properties into three classes: Class A, Class B, or Class C. These classes represent a subjective quality rating of buildings which indicates the competitive ability of each building to attract similar types of tenants. Factors determining the building quality include: rent, building finishes, system standards and efficiency, building amenities, location/accessibility and market perception. See also http://www.boma.org/Resources/classifications/.

cycle (the occupancy rate and the unemployment rate). We are especially interested in the interaction between these variables and building observable attributes such as building type, vintage, structure quality and lease structure. To test for these effects, we estimate stratified regressions, highlighting that our empirical approach is not merely a mechanical engineering exercise but instead represents a reduced-form relationship capturing choices made by self-interested economic decisions makers. For example, if a building features many tenants who face a zero marginal cost for electricity then we expect that electricity consumption will be more sensitive to temperature spikes. We estimate model (1) for all buildings, and then for each property type separately. In each of the five regressions reported in Table II, we include building-fixed effects, and month and year-fixed effects.

We document a concave relationship between a building's occupancy rate and its electricity consumption – buildings that are partially occupied need to be heated or cooled as well, and there seems to be limited flexibility in "switching on or off" parts of a building. In an ideal "smart building," the cooling and lighting is such that areas that are not occupied are not receiving such services. In such a building, electricity consumption will be very low when occupancy rates are low.

Beyond affecting occupancy rates, increases in local unemployment are associated with a reduction in commercial electricity consumption. A one percent increase in the unemployment rate decreases commercial building electricity consumption by about two percent.[12] This may reflect the lower use-intensity of space

[12] The Federal Highway Administration has documented that total miles driven decreased as the 2008 recession took place (http://research.stlouisfed.org/fred2/series/M12MTVUSM227NFWA?rid=254). Our results complement this work and highlight the aggregate energy consumption consequences of business cycles.

(for instance, corporations having reduced presence of employees in the space they occupy).[13]

Columns (2) to (5) present the results stratified by building type. The regression coefficients indicate that industrial real estate seems to be the most responsive to building occupancy (the slope of the occupancy-electricity consumption curve is least concave). Office buildings are least responsive. Presumably, energy consumption in office buildings is for the largest part determined by whole building heating, cooling and ventilation.

At the bottom of Table II, we report the coefficient for a dummy variable that equals one if the building has recently sold. For the full sample, electricity consumption increases by four percent when buildings are transacted. We believe that this variable embodies two offsetting factors. A new owner is likely to make investments to raise the quality of the building. Such investments, including a more efficient HVAC system and more efficient lighting, could make the building more energy efficient. Conversely, improvements in quality that result in better HVAC and lighting systems may induce greater use – a "rebound effect" for commercial buildings.

We plot the coefficients on the temperature-fixed effects in Figure 3, estimating separately the temperature response curves based on building type, vintage, quality, and lease structure.[14] Controlling for occupancy, electricity consumption is higher during those months when it is very hot. The differentials are quite large: for office buildings, monthly consumption is 35 percent higher when the temperature is 97F, on average (the

[13] Recent macroeconomic research by Vernon Henderson et al. (2011) documents a strong correlation between "night lights" and the overall economic performance of an economy.
[14] Following Anin Aroonruengsawat and Maximilian Auffhammer (2011), we split the temperature distribution into deciles, further decomposing the upper and bottom decile into the first, fifth, ninety-fifth and ninety-ninth percentile.

ninety-ninth percentile), relative to when the temperature is 65F. For industrial buildings this differential is less pronounced – the energy consumption is 23 percent higher at the ninety-ninth percentile.

Figures 3B and 3C plot the temperature response curves based on vintage and building quality. Quite clearly, buildings of higher quality and those that were constructed more recently are more responsive to temperature shocks – controlling for occupancy and unemployment and including building-fixed effects. This finding is in line with our "behavioral hypothesis" on a rebound effect in cooling buildings, predicting that new buildings will have higher electricity consumption on hot days than older buildings.

Figure 3D shows how variations in temperature affect commercial building electricity consumption in buildings with different lease structures. In buildings with triple-net leases, tenants are directly responsible for energy costs, whereas in buildings with full service lease contracts, tenants pay a lump sum for total housing costs, including energy and other service costs. The curves show that for buildings where tenants face a zero marginal cost for energy consumption, the response to increases in outside temperature starts at lower temperatures and increases more rapidly. One explanation for this finding may be that the indoor thermostat is set at a lower, more comfortable temperature when tenants do not face a marginal cost for energy consumption.

B. Cross-Sectional Variation in Commercial Building Electricity Consumption

In this section, we report estimates of equation (2). These cross-sectional regressions are informative about the association between building attributes, contract incentives, and management human capital under the standard orthogonality condition. In this case, we must assume that tenants are not sorting on unobserved demand for energy efficiency.[15] To appreciate the implications of this assumption, consider a case in which the commercial real estate pricing gradient is such that more energy efficient buildings and buildings offering a full lease contract command a price premium. In this case, the most energy intensive tenants will self select and choose to locate in the most energy efficient buildings or in buildings for which electricity bills are bundled into the rent. A researcher who estimates electricity consumption regressions using OLS will under-estimate the causal effect of building attributes that reflect energy efficiency because of the tenant mix of "hogs" that will cluster in such "green" buildings.

Our information on the distribution of industries across buildings provides some insight into the extent of tenant sorting based on building quality, energy efficiency, and lease contract structure. Table III provides some descriptive statistics on the average percentage of each of the fourteen of industries in our sample of commercial buildings. Although the industry averages mask the underlying heterogeneity in the energy intensity of individual tenants, these simple statistics give some insight into the sorting of tenant types based on observable characteristics. Panel A shows that government tenants are present in some four percent of the commercial office buildings in our sample. Government tenants, as well as financial services, are clustered into higher quality, Class A buildings.

Although we do not have priors about the energy intensity of industries, one could expect that high tech industries, such as data processing, are more energy intensive,

[15] In the regressions below, we will be controlling for the building's age and size. Our implicit assumption is that within these observable categories, tenants sort "at random" across the buildings. Indeed, Dirk Brounen and Nils Kok (2011) document that private homeowners are uninformed about the thermal quality of residential dwellings – information provided by EU energy performance certificates resolves this information asymmetry and is capitalized at the time of sale. In the case of the California electric utility that we study, there is no equivalent energy performance certificate that is provided to potential tenants of the building or to potential buyers. This suggests that there are significant costs to acquiring information about different buildings' energy efficiency. Given that electricity costs are a relatively small share of a firm's cost of doing business, we expect that few firms will explicitly locate based on this criterion.

whereas tenants in the professional services industry (including legal services, accounting and business services) consume less energy. Panel B provides more insight into the sorting of tenants based on the energy efficiency characteristics and lease contract type of commercial office buildings. Tenants in the data processing industry are more prevalent in less efficient, non-Energy-Star rated buildings, whereas government tenants and the professional service sector seem to sort into more efficient buildings. Tenants from these industries are also more likely to be present in buildings with full-service lease contracts.

In Table IV, we provide the results from estimating equation (2) using monthly data from calendar year 2009 to explaining commercial buildings' electricity consumption. We include month-fixed effects to capture monthly variations in temperature and to account for the peak and off-peak pricing schedule at the utility. We first address how the structural attributes of commercial properties correlate with electricity consumption. The explanatory power of the basic model presented in Column (1) is reasonable, with some 34 percent of the variation explained. Large buildings consume more electricity. Although the coefficient on building size indicates that there is some economies of scale in heating and cooling buildings, the "large building" dummy confirms that buildings larger than 50,000 sq.ft. behave differently than their smaller counterparts, consuming about 30 percent more electricity, on average. Presumably, heating and cooling of large structures requires additional equipment to bridge large vertical distances, offsetting otherwise beneficial economies of scale.

Cohort Effects and Structure Quality

In Column (1), we document that newer buildings consume more electricity. Buildings constructed before 1960 are slightly less efficient than those constructed during the 1960-1970 period, but buildings that are 40 years or younger consistently consume more electricity than old buildings.[16] These findings contrast with results examining vintage effects for residential housing in California that document increased energy efficiency for the most recent vintages (Dora L. Costa and Matthew E. Kahn, 2011). The vintage effect has taken place during a time of declining electricity prices. During the 1960-2010 period, for tenants in commercial buildings, average real electricity prices decreased by fourteen percent.[17]

We note that the electricity consumption of commercial buildings constructed recently (with a vintage less than ten years) is slightly lower as compared to those properties constructed more than ten years ago. (Some have asserted that the recent improvement in energy use intensity is a result of strict legislation, e.g., California's Title 24 building energy efficiency program, but we cannot statistically assess these claims.)

Like vintage, renovation has a distinct effect on commercial building energy consumption. Renovated buildings feature a 27 percent higher electricity consumption than similarly sized buildings. Also, as shown in Column (2) of Table IV, "Class A" real estate consumes twenty percent more electricity than "Class C" real estate.

The findings on building vintage and building quality are consistent with the hypothesis that electricity consumption and building quality are complements, not substitutes. Technological progress may reduce the energy demand from heating, cooling and ventilating the base building, but the increase in appliances and quality attributes

[16] We recognize that at any point in time year built and building age are collinear. We have exploited the panel nature of our 2000 to 2010 data to test for aging effects. In results available on request, we have estimated versions of equation (1) in which we include building fixed effects and an age of building variable. The age coefficient is 0.027 and is statistically insignificant with a *t*-statistic of 0.53. This finding raises our confidence that the year built coefficients we report represent vintage effects rather than a convolution of vintage and aging effects.

[17] Energy Information Agency. Annual Energy Review 2010. See http://205.254.135.24/totalenergy/data/annual/pdf/aer.pdf.

(*e.g.*, a nicer lobby, more elevators, the ability of tenants to independently adapt comfort temperature, etc.) actually *increases* energy consumption. This is comparable to recent work on automobiles, which has documented that technological progress in fuel economy has been partially offset by the increase in vehicle weight and engine power (Christopher R. Knittel, 2012).

Contract Incentives and Human Capital

In Table V, we exploit the rich set of observables in the CoStar database to explore in more detail the role that building occupants, lease structures and human capital play in determining electricity consumption. In column (1), we add a vector of lease contract attributes to the model. The results show that contracting matters for energy consumption: the variable indicating the presence of a triple net lease has a negative coefficient of about 17 percent.[18] This finding is consistent with our hypothesis that tenants facing marginal costs for energy consumption have an incentive to conserve. For occupants with full service rental contracts, energy consumption is significantly higher as compared to occupants with a "modified gross" rental contract, which confirms that energy conservation is negatively affected if tenants do not face the marginal cost of additional consumption.

We can also identify buildings that have a significant share of government occupants. If government tenants have "soft budget constraints," then we predict that such tenants should consume more electricity as they can pass on the costs to taxpayers (Janos Kornai et al., 2003). As shown in column (2) of Table V, the variable measuring

[18] Again, our findings are based on the assumption that lease contract terms are exogenous. If energy-intensive tenants sort into buildings where they face zero marginal cost for electricity consumption, our results reflect a combination of selection and treatment effects, rather than treatment effects alone.

the fraction of a building occupied by a government tenant dummy is positive. If a building is fully occupied by a government tenant, the energy consumption in that building is about 38 percent higher as compared to a building with commercial tenants. This result is obtained when controlled for building quality, but of course, building maintenance and the quality of equipment and appliances cannot be unobserved in our dataset.

In columns (2) and (3), we include a variable measuring the presence of on-site building management. Presumably, human capital is important in building energy efficiency optimization, and having an engineer on-site should be related negatively to commercial building energy consumption. Especially for buildings with a full-service lease structure, owners should be aware of the adverse incentive effects and they should have a greater incentive to invest in costly building management to increase energy efficiency. On-site management is present for some 17 percent of full-service buildings, whereas on-site management is present for just two percent of triple-net buildings.[19] The coefficient for "On-Site Management" shows that building management has a positive effect on commercial building energy efficiency, reducing energy consumption by some 7-8 percent – this finding is in line with the impact of management quality at corporations on the energy intensity of manufacturing plants, as documented by Nicholas Bloom et al. (2011).

The number of "green" buildings (certified by US Green Building Council and/or the DOE) has been growing rapidly over the past decade (Nils Kok et al., 2011), but the actual energy efficiency of such buildings has been subject to popular debate. To further investigate this issue, we match our dataset with the Energy-Star-files maintained by the

[19] A *t*-test shows that the difference between these means is statistically significant from zero at the 1-percent level.

EPA and the DOE. A very small fraction of the properties in our dataset has obtained an Energy Star label – some thirty buildings. In columns (3) and (4), we add a binary variable indicating the award of an Energy Star. The results show that, in a fully occupied building, an Energy-Star-labeled building consumes some 34 percent less energy as compared to an otherwise similar building. This is surprisingly similar to conservation claims made by the EPA (the Energy Star label is marketed as a commitment to conservation and environmental stewardship, but it is also touted as a vehicle for reducing building costs and for demonstrating superior management skill).

V. Conclusion

The durable building stock in the United States is a major consumer of electricity. The Energy Information Agency predicts that between the years 2005 and 2030, residential electricity consumption will increase by 39 percent, industrial consumption will increase by 17 percent, and commercial electricity consumption will increase by 63 percent.[20] In the absence of a carbon tax, such increased consumption will have significant greenhouse gas externality consequences. Given these facts, it is surprising how little we know about commercial building electricity consumption. Data collection has hindered such research, as micro data on commercial building energy consumption is rare. (The only such source, the CBECS data assembled by the DOE, is now nine years out of date.) To fill this void, we partnered with a major California electric utility and merged information on electricity consumption at the building level with detailed physical attributes of the building. Using panel data on each building's monthly

[20] See page 82 of the U.S. Energy Information Administration's *Annual Energy Outlook 2007 With Projections to 2030*. ftp://tonto.eia.doe.gov/forecasting/0383(2007).pdf

electricity consumption, we test a number of hypotheses seeking to investigate the time series and cross-sectional determinants of electricity consumption.

We document that, since 1970, there is an inverse relation between building vintage (and quality) and electricity consumption. Moreover, newer, high-quality building respond faster to changes in outdoor temperature, leading to increased energy consumption. These findings stand in contrast with evidence on energy consumption trends for residential structures: it has been documented for homes that new vintages have lower electricity consumption, controlling for interior square footage.

We have four explanations for our results. First, although building codes for commercial buildings have been developed and implemented in some states across the nation,[21] increases in the energy efficiency of commercial buildings (through new construction and retrofits of existing structures) mainly affects energy consumption for space heating (and, to a lesser extent, space cooling). Energy consumption from air-conditioning, lighting and "other uses" are not affected. Building codes thus have an impact on a very small fraction of total building energy consumption.[22] Second, and closely related, the composition of the energy mix used in buildings has changed quite substantially over the past decades. The natural gas intensity has been falling as a result of fuel switching from end uses formerly fueled by gas (*e.g.*, cooking and water heating), which has lead to an increase in electricity consumption. Third, the "computerization" of society is thought to comprise a significant amount of the recent increase in electricity use in the commercial building sector. This includes the accelerated diffusion of personal

[21] The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) started to develop commercial building energy codes in 1975. These codes are known as "Standard 90.1." Since the passage of the Energy Policy Act in 1992, the Department of Energy (DOE) is responsible for tracking progress in the adoption of building codes. The latest commercial building code aims to achieve a 25 percent reduction in energy consumption over the standard adopted in 1975.

[22] See David B. Belzer et al. 2004. "Analysis of U.S. Commercial Building Energy Use Trends, 1972-1991." Richland (WA): Pacific Northwest Laboratory.

computers, printers, copiers and other equipment that was virtually non-existent before 1960. Fourth, in buildings with more efficient heating, cooling and ventilation systems, the behavioral response of building tenants may lead to more intensive use of such equipment, as the marginal price of “comfort” is lower – a “rebound” effect for commercial buildings.

Our finding of a positive correlation between commercial building quality and electricity consumption means that the commercial’s share of total electricity consumption is likely to rise over time both due to a declining residential share and rising commercial consumption. This suggests that future energy efficiency policies must focus more explicitly on the commercial sector, using not just prescriptive building codes and voluntary “green” certification programs, but also by explicitly taking into account the behavioral response of occupants.

Our results on building management offer a more optimistic message. If human capital, reflected in better building management, yields improved environmental performance in commercial structures, then nudging building owners towards having a well-trained, experienced building management team makes the energy decisions auger well for future improved environmental outcomes.

References

Aroonruengsawat, Anin and Maximilian Auffhammer. 2011. "Simulating California's Future Residential Electricity Consumption under Different Scenarios of Climate Change." *Climatic Change*, 111(2), 411-24.

Bloom, Nicholas; Christos Genakos; Ralf Martin and Raffaella Sadun. 2011. "Modern Management: Good for the Environment, or Just Hot Air?" *Economic Journal*, 120, 551-72.

Brounen, Dirk and Nils Kok. 2011. "On the Economics of Energy Efficiency in the Housing Market." *Journal of Environmental Economics and Management*, 62, 166-79.

Brounen, Dirk; Nils Kok and John M. Quigley. 2012. "Residential Energy Use and Conservation: Economics and Demographics." *European Economic Review*, 56(5), 931-45.

Costa, Dora L. and Matthew E. Kahn. 2011. "Electricity Consumption and Durable Housing: Understanding Cohort Effects." *American Economic Review*, 101(3), 88-92.

Davis, Lucas W. 2008. "Durable Goods and Residential Demand for Energy and Water: Evidence from a Field Trial." *RAND Journal of Economics*, 39(2), 530-46.

Eichholtz, Piet M.A.; Nils Kok and John M. Quigley. 2010. "Doing Well by Doing Good: Green Office Buildings." *American Economic Review*, 100(5), 2494–511.

Glaeser, Edward L. and Matthew E. Kahn. 2010. "The Greenness of Cities: Carbon Dioxide Emissions and Urban Development." *Journal of Urban Economics*, 67(3), 404-18.

Gould, Eric D. ; B. Peter Pashigian and Canice J. Prendergast. 2005. "Contracts, Externalities, and Incentives in Shopping Malls." *Review of Economics and Statistics*, 87(3), 411–22.

Greening, Lorna; David L. Greene and Carmen Difiglio. 2000. "Energy Efficiency and Consumption—the Rebound Effect—a Survey." *Energy Policy*, 6, 389-401.

Henderson, Vernon; Adam Storeygard and David N. Weil. 2011. "A Bright Idea for Measuring Economic Growth." *American Economic Review*, 101(3), 194-99.

Hirst, Eric and Jerry Jackson. 1977. "Historical Patterns of Residential and Commercial Energy Uses." *Energy*, 2(2), 131-40.

Ito, Koichiro. 2012. "Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing," *NBER Working Paper #18533.*

Jacobsen, Grant D. and Matthew J. Kotchen. 2013. "Do Building Energy Codes Matter? Evidence from Florida." *Review of Economics and Statistics*, 95(1).

Jaffee, Dwight; Richard Stanton and Nancy Wallace. 2012. "Energy Factors, Leasing Structure and the Market Price of Office Buildings in the U.S.," *AREUEA Annual Meeting.* Chicago.

Kahn, Matthew E. and Joel Schwartz. 2008. "Urban Air Pollution Progress Despite Sprawl: The "Greening" of the Vehicle Fleet." *Journal of Urban Economics*, 63(3), 775-87.

Knittel, Christopher R. 2012. "Automobiles on Steriods: Product Attribute Trade-Offs and Technological Progress in the Automobile Sector." *American Economic Review*, 101(7), 3368-99.

Kok, Nils; Marquise McGraw and John M. Quigley. 2011. "The Diffusion of Energy Efficiency in Building." *American Economic Review*, 101(3), 77–82.

Kornai, Janos; Eric Maskin and Gerard Roland. 2003. "Understanding the Soft Budget Constraint." *Journal of Economic Literature*, 41(4), 1095-136.

Kotchen, Matthew J. and Erin T. Mansur. 2012. "How Stringent Is the Epa's Proposed Carbon Pollution Standard for New Power Plants?" *Review of Environmental Economics and Policy*, forthcoming.

Levinson, Arik and Scott Niemann. 2004. "Energy Use by Apartment Tenants When Landlords Pay for Utilities." *Resource and Energy Economics*, 26(1), 51-75.

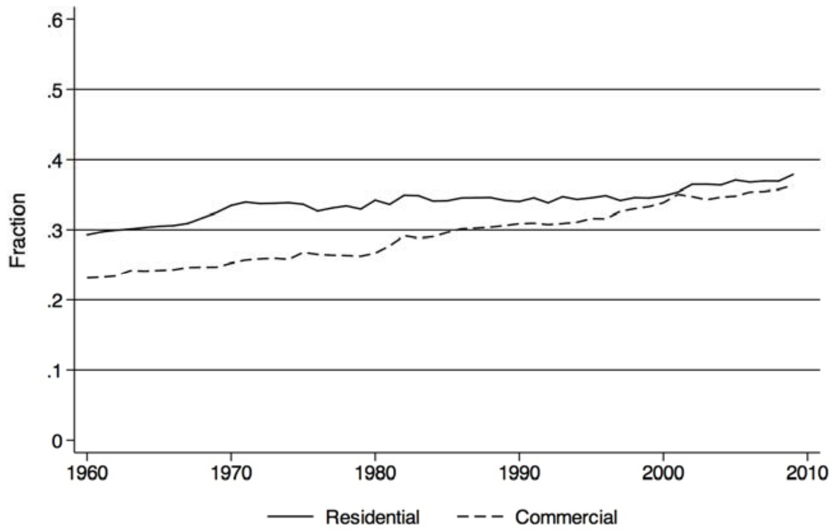
Reiss, Peter C. and Matthew W. White. 2005. "Household Electricity Demand, Revisited." *Review of Economic Studies*, 72(3), 853-83.

____. 2008. "What Changes Energy Consumption? Prices and Public Pressures." *RAND Journal of Economics*, 39(3), 636-63.

Small, Kenneth A. and Kurt Van Dender. 2007. "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect." *Energy Journal*, 28, 25-51.

Figure 1
Fraction of Electricity Consumed in Residential and Commercial Buildings
(1960-2009)

A. United States



B. California

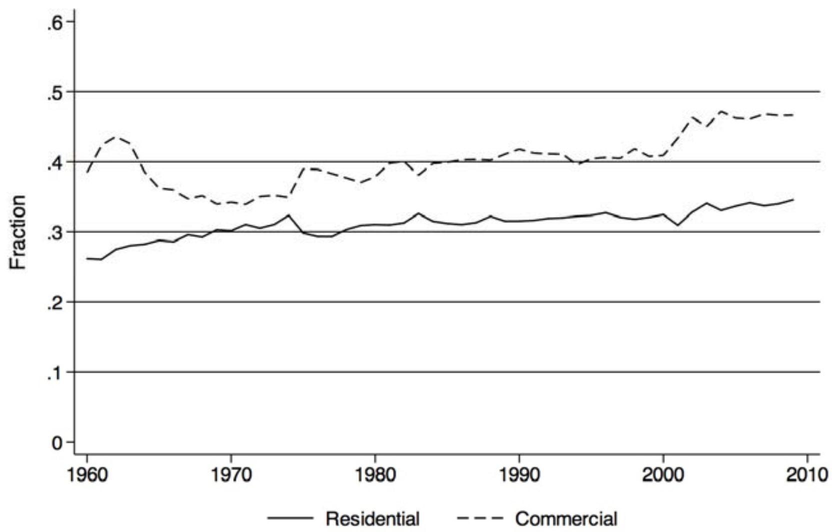


Figure 2
Decomposition of Commercial Building Electricity Consumption

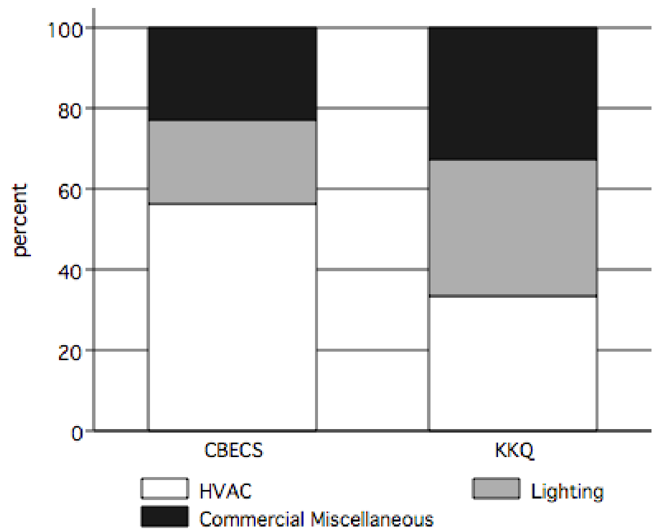
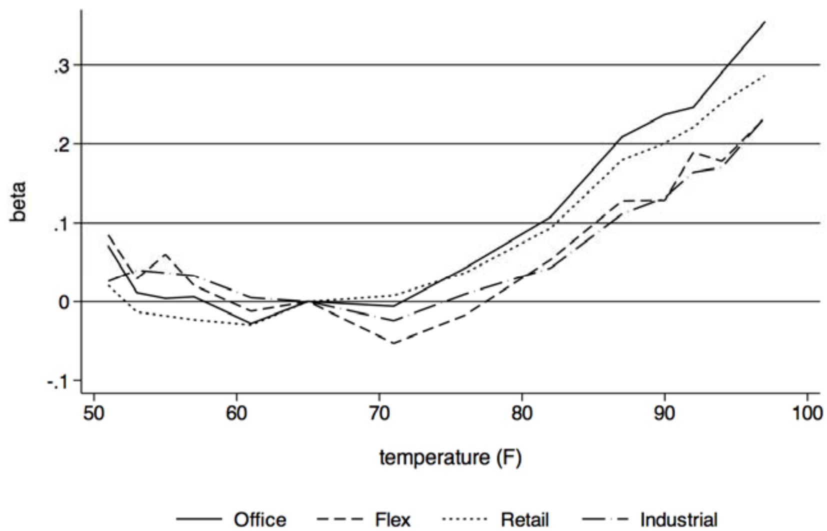
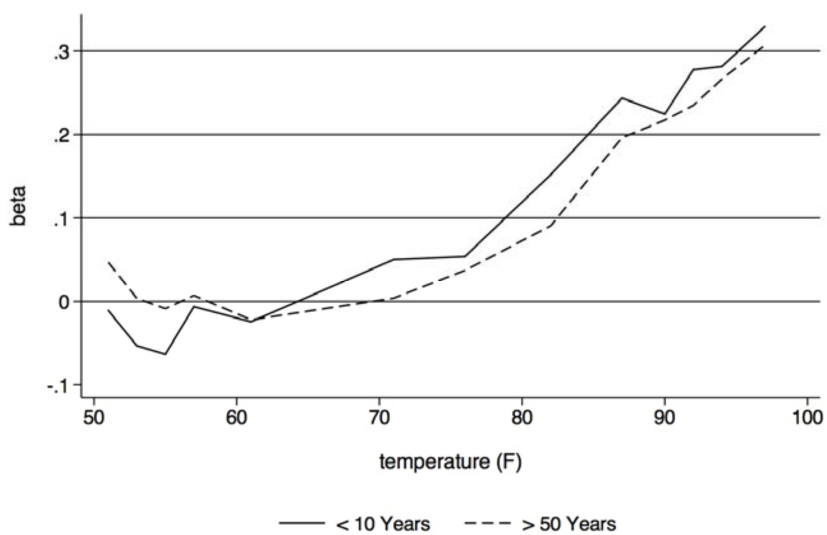


Figure 3
Temperature Response Estimations
(coefficients based on Table II)

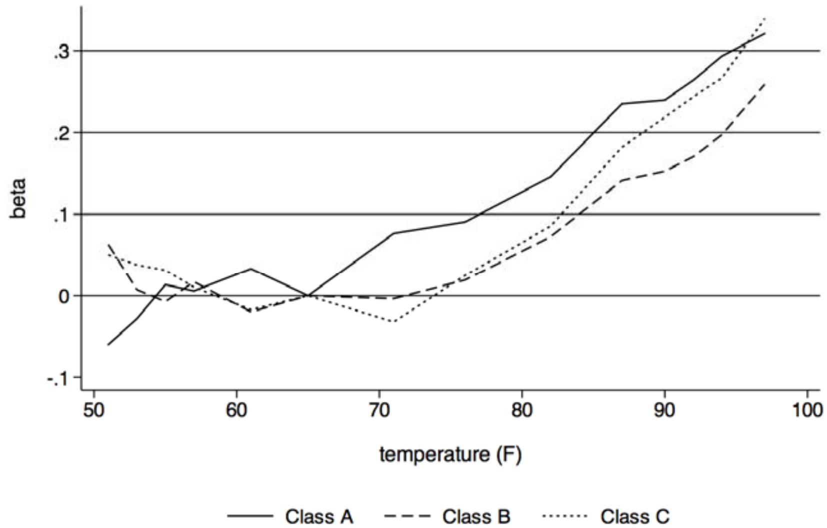
A. Building Type



B. Age



C. Building Quality



D. Lease Contract

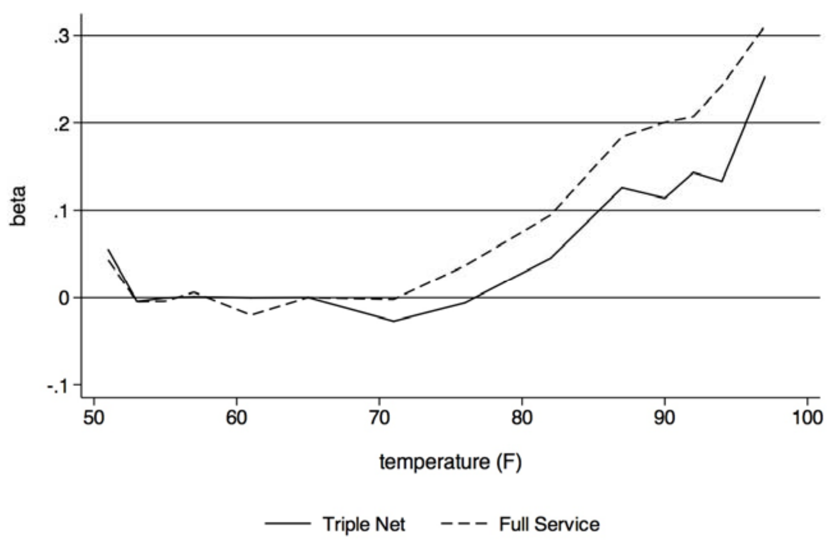


Table I
Commercial Building Energy Consumption
(Office, Flex, Industrial and Retail Properties, 2009)

	Office (n=1,478)		Flex (n=322)		Industrial (n=1,120)		Retail (n=601)	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Energy & Climate								
Daily Expenditures ($)	131.88	(292.02)	95.00	(449.29)	46.24	(99.33)	100.53	(357.43)
Daily Consumption (kWh)	1193.85	(2821.93)	905.13	(5280.95)	383.15	(891.16)	878.96	(3055.12)
Number of Accounts	3.22	(6.71)	6.10	(8.66)	4.14	(6.08)	5.01	(22.66)
Monthly Temperature (F, Maximum)	74.70	(13.60)	74.78	(13.63)	74.75	(13.59)	74.69	(13.58)
Building Characteristics								
Building Size (in thousands of sq.ft.)	27.75	(48.66)	21.88	(19.45)	32.37	(59.82)	16.24	(46.94)
Class A (percent)	6.35	(24.38)	0.00	(0.00)	3.31	(17.88)	-	-
Class B (percent)	39.47	(48.88)	44.78	(49.73)	38.14	(48.57)	-	-
Class C (percent)	54.18	(49.83)	42.47	(49.44)	58.38	(49.30)	-	-
Age (years)	27.42	(20.33)	22.93	(11.88)	24.61	(15.42)	35.63	(25.75)
Renovated (percent)	7.85	(26.90)	2.80	(16.50)	1.43	(11.87)	5.76	(23.30)
Number of Stories	1.90	(2.21)	1.07	(0.26)	1.02	(0.12)	1.16	(0.48)
Distance to CBD (in km)	12.77	(10.01)	12.92	(7.34)	12.75	(7.34)	7.59	(4.73)
Occupancy								
Occupancy Rate (percent)	80.66	(29.73)	73.49	(33.68)	77.86	(34.44)	87.49	(26.70)
Government Tenants (1=yes)	7.85	(26.89)	4.66	(21.09)	1.16	(10.72)	0.31	(5.54)
Space Occupied by Government (percent)	49.09	(36.89)	66.21	(39.37)	-	-	29.02	(13.52)
Rents & Contract Type								
Total Asking Rent ($ per sq.ft.)	20.10	(5.81)	10.40	(3.78)	6.30	(2.65)	19.24	(7.47)
Total Gross Rent ($ per sq.ft.)	21.05	(5.81)	-	-	12.00	(0.00)	22.70	(0.91)
Triple Net (percent)	7.06	(25.61)	37.02	(48.30)	29.63	(45.67)	26.75	(44.27)
Modified Gross (percent)	10.41	(30.54)	16.60	(37.21)	18.27	(38.64)	3.59	(18.60)
Full Service (percent)	34.31	(47.48)	3.17	(17.53)	1.07	(10.30)	1.51	(12.21)

Table II
Time Trends in Commercial Building Energy Consumption
(Dependent Variable: Logarithm of Electricity Consumption per Square Foot, kWh, 2000 – 2010)

	(1) All Buildings	(2) Office	(3) Flex	(4) Industrial	(5) Retail
Occupancy Rate	2.194***	2.310***	1.895***	1.760***	2.465***
(percent)	[0.023]	[0.031]	[0.070]	[0.047]	[0.066]
Occupancy Rate^2	-1.064***	-1.101***	-0.727***	-0.711***	-1.482***
	[0.019]	[0.026]	[0.059]	[0.042]	[0.053]
Unemployment Rate	-0.019***	-0.016***	-0.016	-0.025***	-0.012*
(percent)	[0.003]	[0.004]	[0.010]	[0.006]	[0.007]
Transaction Dummy	0.042***	0.045***	0.022	0.015	0.053***
(1=yes)	[0.005]	[0.007]	[0.018]	[0.011]	[0.012]
Constant	-4.819***	-4.618***	-5.106***	-5.526***	-4.369***
	[0.016]	[0.022]	[0.055]	[0.033]	[0.064]
Temperature-Fixed Effects	Y	Y	Y	Y	Y
Month-Fixed Effects	Y	Y	Y	Y	Y
Year-Fixed Effects	Y	Y	Y	Y	Y
Building-Fixed Effects	Y	Y	Y	Y	Y
Observations	302,186	144,155	21,971	75,078	60,982
R-squared	0.139	0.178	0.215	0.137	0.077
Number of Buildings	2,992	1,439	211	742	600

Standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table III
Tenant Sorting in Commercial Buildings
(Building Type, Energy Star and Lease Structure, 2009)

Panel A. Commercial Building Type

Industry of Tenant	Overall	Building Class: Class A	Class B	Class C	Property Type: Office	Retail	Flex	Industrial
Agri/Mining/Utilities	5.18	2.55	6.02	7.14	2.59	0.00	9.22	11.31
Communications	0.94	3.79	1.17	0.90	1.14	0.00	1.70	1.00
Data processing	1.55	3.22	2.64	1.18	2.26	0.00	4.46	0.53
Distribution	8.85	5.34	9.26	12.70	3.00	0.04	10.47	23.23
Financial Services	10.17	17.89	11.34	10.59	19.16	5.84	3.39	1.55
Government	4.30	15.28	6.11	3.52	7.72	0.48	5.29	1.28
Manufacturing	5.93	6.57	6.75	7.68	1.49	0.14	13.03	14.31
Medical Services	6.85	4.57	9.22	8.25	14.27	0.38	5.01	0.40
Non-profits	0.12	0.00	0.14	0.09	0.17	0.20	0.10	0.00
Professional Services	9.50	14.62	12.09	10.74	16.71	0.25	9.00	4.80
Retail	7.79	0.00	0.64	0.24	0.12	39.34	0.37	0.79
Services	17.04	13.43	16.91	19.69	18.08	11.86	20.12	17.91
Transportation	1.44	0.84	1.50	2.14	0.66	0.00	0.54	3.90
Personal Services	13.98	12.75	15.82	18.64	17.82	0.21	17.62	16.13
Other	20.34	11.90	16.22	15.12	12.63	41.47	17.32	18.97

Panel B. Energy Star Buildings and Lease Structure

Industry of Tenant	Non-Energy Star Mean	Non-Energy Star Std.Dev.	Energy Star Mean	Energy Star Std.Dev.	Full Service Mean	Full Service Std.Dev.	Triple Net Mean	Triple Net Std.Dev.
Agri/Mining/Utilities	2.60	(13.98)	1.41	(3.87)	2.55	(12.60)	2.08	(12.70)
Communications	1.05	(9.07)	2.91	(8.19)	0.68	(4.82)	0.18	(1.25)
Data processing	2.21	(11.83)	1.04	(5.02)	2.61	(11.60)	0.90	(6.43)
Distribution	2.91	(13.04)	2.74	(6.24)	2.23	(8.54)	6.12	(21.37)
Financial Services	19.41	(32.99)	17.03	(22.83)	23.86	(32.53)	23.36	(38.50)
Government	6.89	(23.22)	30.07	(36.29)	10.24	(25.91)	0.41	(4.16)
Manufacturing	1.51	(10.20)	0.53	(1.29)	1.65	(8.74)	2.15	(13.85)
Medical Services	14.75	(32.25)	0.11	(0.53)	9.62	(24.49)	10.37	(27.39)
Non-profits	0.20	(3.25)	0.29	(1.45)	0.11	(1.37)	0.77	(5.57)
Professional Services	16.43	(30.61)	23.05	(27.17)	19.51	(28.40)	9.28	(23.70)
Retail	0.11	(2.12)	-	-	0.08	(1.49)	0.13	(1.88)
Services	0.28	(3.88)	-	-	0.21	(2.09)	0.15	(2.21)
Transportation	0.71	(7.04)	0.30	(1.50)	0.50	(3.83)	0.09	(1.22)
Personal Services	17.77	(33.24)	8.51	(12.48)	14.64	(26.74)	15.33	(32.36)
Other	13.17	(29.28)	12.02	(26.08)	11.53	(23.46)	28.68	(39.13)

Table IV
Determinants of Commercial Building Energy Consumption
(Dependent Variable: Logarithm of Daily Electricity Consumption per Square Foot, 2009)

	(1)	(2)	(3)	(4)
Occupancy Rate	3.713***	3.715***	3.627***	1.175***
(percent)	[0.082]	[0.082]	[0.082]	[0.070]
Occupancy Rate^2	-2.146***	-2.131***	-2.046***	-0.536***
	[0.072]	[0.072]	[0.072]	[0.061]
Building Size	-0.099***	-0.114***	-0.116***	
(log)	[0.007]	[0.007]	[0.007]	
Large Building Dummy	0.300***	0.254***	0.265***	
(> 50,000 sq.ft.)	[0.023]	[0.024]	[0.023]	
Vintage[#]				
Age < 10 Years	0.296***	0.252***	0.188***	
(1=yes)	[0.020]	[0.022]	[0.022]	
Age 10-20 Years	0.465***	0.452***	0.417***	
(1=yes)	[0.023]	[0.023]	[0.023]	
Age 20-30 Years	0.274***	0.289***	0.267***	
(1=yes)	[0.018]	[0.018]	[0.018]	
Age 30-40 Years	0.145***	0.167***	0.177***	
(1=yes)	[0.020]	[0.020]	[0.020]	
Age 40-50 Years	-0.066**	-0.054**	-0.031	
(1=yes)	[0.027]	[0.027]	[0.027]	
Renovated	0.262***	0.250***	0.268***	
(1=yes)	[0.026]	[0.026]	[0.026]	
Stories[##]				
2-4		0.262***	0.341***	
(1=yes)		[0.043]	[0.043]	
> 4		0.036**	0.082***	
(1=yes)		[0.016]	[0.016]	
Building Quality[###]				
Class A		0.202***	0.203***	
(1=yes)		[0.036]	[0.036]	
Class B		0.117***	0.101***	
(1=yes)		[0.015]	[0.015]	
Distance to CBD			0.011***	
(in kilometers)			[0.001]	
Constant	-4.507***	-4.453***	-4.523***	-4.547***
	[0.071]	[0.071]	[0.071]	[0.019]
Temperature-Fixed Effects	Y	Y	Y	Y
Month-Fixed Effects	Y	Y	Y	Y
Building-Fixed Effects	N	N	N	Y
Observations	34,032	34,032	34,020	34,032
R-squared	0.344	0.347	0.351	
Adj R^2	0.344	0.346	0.350	
Number of Buildings				2,897

[#] Omitted: “Age > 50 Years,” [##] Omitted: “Single Story,” [###] Omitted: “Class C”

Standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table V
Commercial Building Energy Consumption, Contracts and Tenants
(Dependent Variable: Logarithm of Daily Electricity Consumption per Square Foot, kWh, 2009)

	(1)	(2)	(3)	(4)
Occupancy Rate	3.214***	3.267***	3.286***	1.486***
(percent)	[0.088]	[0.088]	[0.088]	[0.080]
Occupancy Rate^2	-1.748***	-1.804***	-1.809***	-0.753***
(percent)	[0.077]	[0.077]	[0.077]	[0.068]
Building Size	-0.117***	-0.126***	-0.125***	
(log)	[0.009]	[0.009]	[0.009]	
Large Building Dummy	0.174***	0.174***	0.169***	
(> 50,000 sq.ft.)	[0.024]	[0.024]	[0.024]	
Rental Contract				
Triple Net	-0.168***	-0.167***	-0.163***	
(1=yes)	[0.018]	[0.018]	[0.018]	
Full Service	0.112***	0.114***	0.111***	
(1=yes)	[0.020]	[0.020]	[0.020]	
Number of Accounts	0.018***	0.018***	0.018***	
(1=yes)	[0.001]	[0.001]	[0.001]	
Fraction Occupied by Government		0.378***	0.392***	
(percent)		[0.043]	[0.043]	
On-Site Management		-0.081***	-0.068**	
(1=yes)		[0.031]	[0.031]	
Energy Star Labeled			1.372***	
(1=yes)			[0.198]	
Energy Star Labeled*Occupancy Rate			-1.711***	-0.526**
			[0.233]	[0.221]
Constant	-3.401***	-3.330***	-3.355***	-4.792***
	[0.194]	[0.194]	[0.194]	[0.025]
Other Controls	Y	Y	Y	Y
Temperature-Fixed Effects	Y	Y	Y	Y
Month-Fixed Effects	Y	Y	Y	Y
Building-Fixed Effects	N	N	N	Y
Observations	26,023	26,023	26,023	26,023
R-squared	0.425	0.427	0.428	
Adj R^2	0.423	0.425	0.426	
Number of Buildings				2,205

"Other controls" include vintage indicators, quality indicators, number of stories and distance to CBD. Column (4) also includes building-fixed effects.

Standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1