Carbon Emissions from the Commercial Building Sector: The Role of Climate, Vintage, and Incentives

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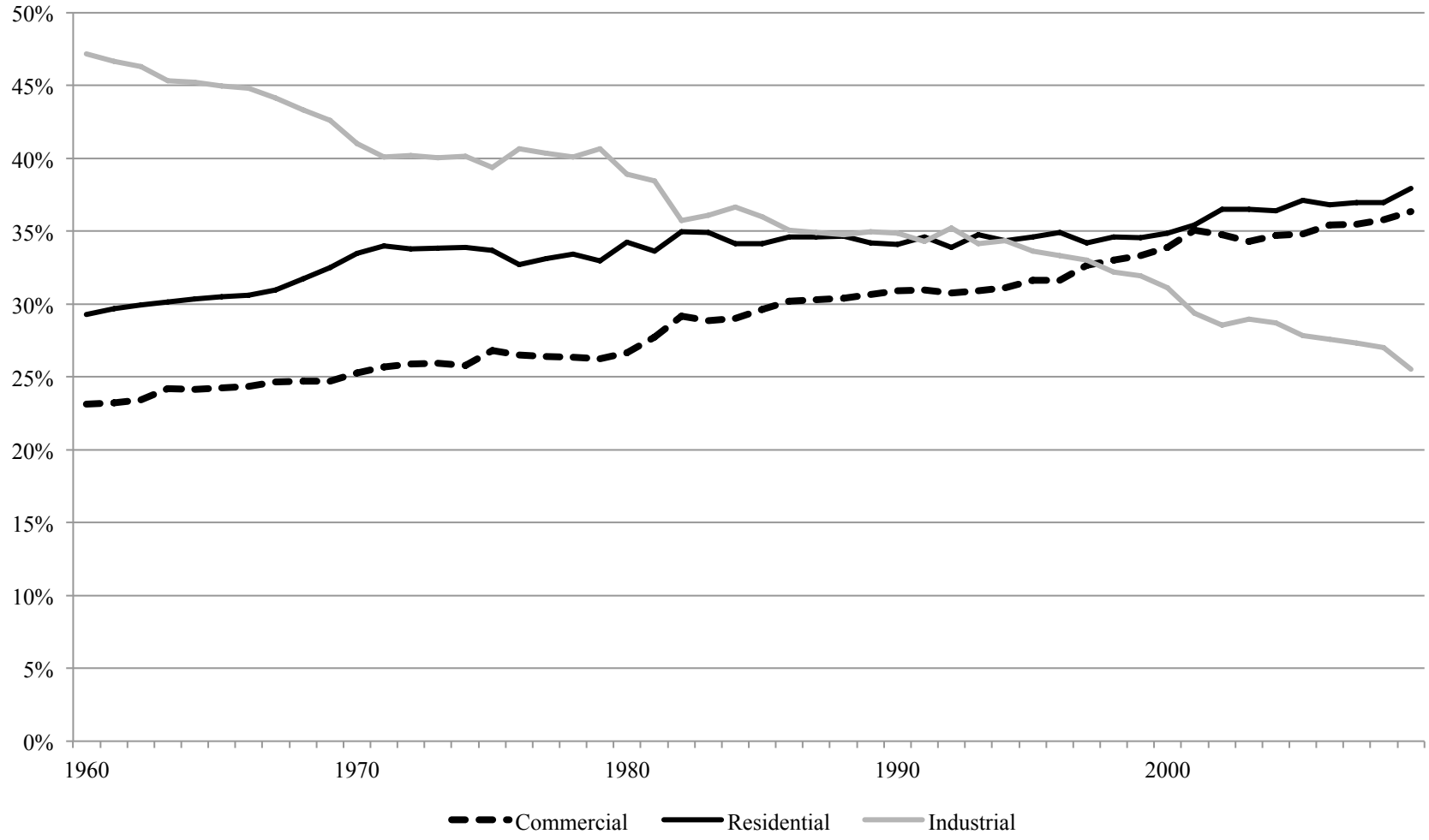
74% of US electricity used in real estate sector

40 percent generated using coal, 29 percent using natural gas



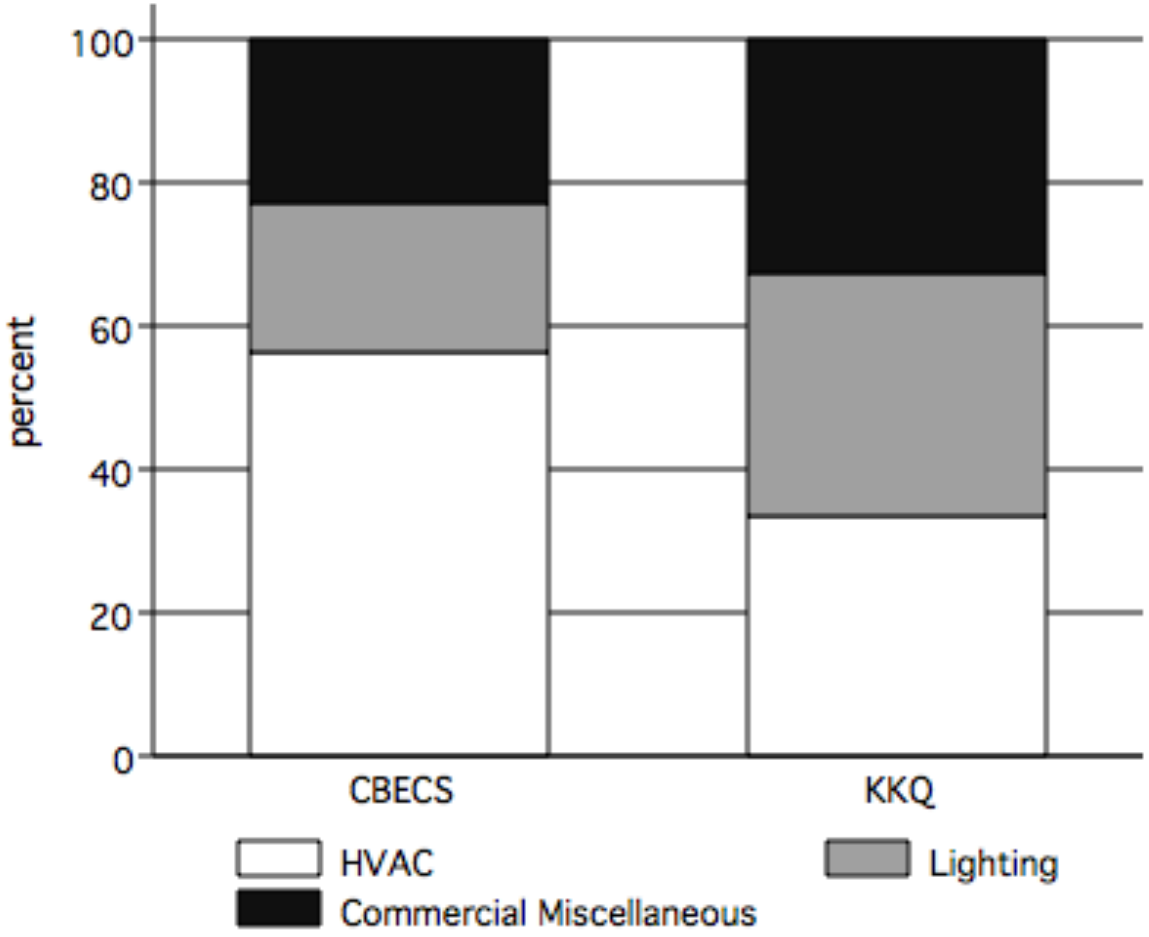
Energy conservation in commercial property

An understudied area (in economics)

- Much of current debate on energy efficiency focuses on residential sector (labels, regulation, incentives, nudges, shocks, …)
  - Brounen et al. (2012, in press), Kotchen and Jacobsen (2013), Reiss and White (2005), Alcott (2011)
- Literature on energy efficiency in commercial real estate focuses mostly on financial implications of (green) labels…
  - Eichholtz et al. (2010, 2013)
- Commercial buildings are chunky so large effects by "treating" a small group, but…what determines electricity consumption in commercial buildings?
  - Information from CBECS and engineering sources is limited, technical and outdated

Decomposition of building electricity use

What explains cross-sectional and temporal variation?



This paper

Explaining commercial building electricity consumption

Commercial building electricity consumption is a function of:

1. Construction characteristics
   - Square footage
   - Quality of HVAC systems, lighting, etc.
   - Vintage
     - Building codes (Papineau, 2013)
     - Does technological progress reduce energy consumption? (Knittel 2012)
   - Unobservables (e.g., architecture, amenities)

2. Tenant behavior and tenant incentives
   - Lease contracts: define how payments are allocated and may affect economic performance (Gould et al., 2005)
     - Full gross (zero marginal cost)
     - Modified gross (pro-rated share)
     - (Triple) net
   - Occupants and their behavior (tenants, appliances)
     - Government tenants (soft budget constraints)

Empirical framework (II)

Explaining commercial building electricity consumption

Commercial building electricity consumption is a function of:

4. Human capital
   - On-site building manager may affect energy consumption (comparable to human capital of managers in manufacturing plants, Bloom et al., 2011)

5. Macro conditions
   - Climatic conditions
     - Tenant response dependent on building quality, type and lease contract: “rebound effect”? (Van Dender and Small, 2007; Davis, 2008)
   - Economic conditions (business cycle)

Data

Unique panel on consumption, quality and contracts

50,000 commercial accounts in service area of a utility, merged with CoStar database – 38,906 accounts in 3,521 buildings over 2000 – 2010 period.

- **Energy consumption** — **Billing information**
  Electricity use per account per building (kWh)
  monthly data transformed into daily consumption
- **Structure data** — **Hedonic characteristics**
  CoStar
  Vintage, size, property type (no multi-family), location, quality
  Occupancy rate
- **Behavioral data** — **Property "demographics"**
  CoStar
  Tenant (SIC code), building manager, lease contract (triple net, full gross, …)
- **Other data**
  Climatic conditions (NOAA) measured by average maximum temp, business cycle (unemployment rate)

Descriptive statistics

Commercial stock is young relative to residential dwellings

	Office (n=1,478)	
	mean	sd
Energy & Climate		
Daily Expenditures ($)	131.88	(292.02)
Daily Consumption (kWh)	1193.85	(2821.93)
Number of Accounts	3.22	(6.71)
Monthly Temperature (F, Maximum)	74.70	(13.60)
Building Characteristics		
Building Size (in thousands of sq.ft.)	27.75	(48.66)
Class A (percent)	6.35	(24.38)
Class B (percent)	39.47	(48.88)
Class C (percent)	54.18	(49.83)
Age (years)	27.42	(20.33)
Renovated (percent)	7.85	(26.90)
Number of Stories	1.90	(2.21)
Distance to Capitol (in km)	12.77	(10.01)
Occupancy		
Occupancy Rate (percent)	80.66	(29.73)
Government Tenants (1=yes)	7.85	(26.89)
Space Occupied by Government (percent)	49.09	(36.89)
Rents & Contract Type		
Total Asking Rent ($ per sq.ft.)	20.10	(5.81)
Total Gross Rent ($ per sq.ft.)	21.05	(5.81)
Triple Net (percent)	7.06	(25.61)
Modified Gross (percent)	10.41	(30.54)
Full Service (percent)	34.31	(47.48)

Model specification (I)

Cross-sectional analysis: consumption variation

- The cross-sectional variation in commercial building energy consumption:

(1) $$\ln y_i = \gamma \cdot \mathrm{X}_i + \sum_{n=1}^{k} \varphi_p \cdot T_i^n + \varepsilon_i$$

  - y_i is the average daily energy consumption per sq.ft. (in kWh)
  - X_t is a vector of structural characteristics of building *I*
  - *T* represents share of tenant *n* in building *i*
  - Month-fixed effects (capturing weather and price variation)

- We assume no tenant sorting based on energy efficiency or contract characteristics. No information on electricity prices.

Regression results

Cohort effects and building quality

	(1)
Building Size	-0.505***
(log)	[0.075]
Building Size^2	0.026***
(log)	[0.004]
Vintage[#]	
Age < 10 Years	0.098***
(1=yes)	[0.022]
Age 10-20 Years	0.157***
(1=yes)	[0.024]
Age 20-30 Years	0.105***
(1=yes)	[0.020]
Age 30-40 Years	-0.006
(1=yes)	[0.022]
Age 40-50 Years	-0.089***
(1=yes)	[0.031]
Renovated	0.204***
(1=yes)	[0.023]
Constant	-2.679***
	[0.368]
Observations	21,053
R-squared	0.399
Adj R^2	0.397

- Some economies of scale in larger buildings
  - One st. dev. increase in size reduces consumption by 1.7%
- Vintage *negatively* related to electricity consumption
  - Exception: < 1970
  - Strongly contrasting findings for residential dwellings
  - Very recent buildings seem to perform better

Regression results

Cohort effects and building quality

	(2)
Stories[##]	
2-4	0.027
(1=yes)	[0.016]
> 4	0.241***
(1=yes)	[0.048]
Building Quality[###]	
Class A	0.195***
(1=yes)	[0.032]
Class B	0.118***
(1=yes)	[0.015]
Constant	-3.296***
	[0.383]
Observations	21,053
R-squared	0.402
Adj R^2	0.401

- Building quality and electricity consumption are complements, not substitutes. Comparable to vehicle weight and engine power (partially) offsetting technological progress in vehicles (Knittel, 2012)

Regression results

Contract terms and human capital

	(3)	(4)
Rental Contract		
Triple Net	-0.284***	-0.274***
(1=yes)	[0.019]	[0.019]
Modified Gross	-0.346***	-0.324***
(1=yes)	[0.021]	[0.021]
Full Service	0.027	0.031
(1=yes)	[0.020]	[0.020]
Fraction Occupied by Government		0.360***
(percent)		[0.044]
On-Site Management		-0.084***
(1=yes)		[0.027]
Constant	-2.751***	-3.165***
	[0.382]	[0.380]
Observations	21,053	20,969
R-squared	0.411	0.415
Adj R^2	0.410	0.414

- Facing a marginal cost for energy consumption matters for tenants (Levinson and Niemann, 2004)
- "Soft budget constraints" of government increase energy consumption
- Human capital seems to be important in building energy optimization (Bloom et al., 2011)

Model specification (II)

Panel analysis: consumption dynamics

- The longitudinal variation in commercial building energy consumption:

(2) $$\ln y_{it} = \sum_{p=1}^{k} \beta_p \cdot D_{it}^{p} + \gamma \cdot \mathrm{Z}_{it} + \alpha_i + \theta_m + \lambda_y + \eta_{it}$$

  - y_{it} is the average daily energy consumption per sq.ft. in month *t* (in kWh)
  - D_t is a vector of temperature dummies
  - Z_{it} is the occupancy rate in building *i* in month *t* and the local unemployment rate (reflecting business cycle)
  - $\alpha_i, \beta_y, \tau_m$ capture building-fixed effects, year-fixed effects and month-fixed-effects, respectively
  - Standard errors clustered at the property level

Regression results

Concave effect occupancy rate on electricity consumption

	(1) All Buildings	(2) Office	(3) Flex	(4) Industrial	(5) Retail
Occupancy Rate (fraction)	2.189***	2.306***	1.855***	1.759***	2.481***
	[0.132]	[0.178]	[0.475]	[0.249]	[0.397]
Occupancy Rate^2 (fraction)	-1.059***	-1.095***	-0.703**	-0.710***	-1.494***
	[0.094]	[0.128]	[0.339]	[0.184]	[0.265]
Unemployment Rate (percent)	-0.016***	-0.012***	-0.013	-0.024***	-0.010
	[0.003]	[0.004]	[0.009]	[0.007]	[0.007]
Transaction Dummy (1=yes)	0.042***	0.045***	0.030	0.015	0.056**
	[0.011]	[0.015]	[0.044]	[0.026]	[0.025]
Constant	-4.860***	-4.653***	-5.130***	-5.538***	-4.380***
	[0.046]	[0.062]	[0.157]	[0.088]	[0.146]
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	299,726	143,704	21,889	75,007	59,126
R-squared (within)	0.140	0.179	0.217	0.137	0.078
Number of Buildings	2,976	1,430	208	742	596

Regression results explained

Dynamics have important effect on consumption

- Non-linear relation between occupancy and energy use – empty buildings consume energy as well…
  - Industrial buildings most responsive
- Building transaction increase energy consumption: investments in new systems may be offset by behavior of tenants
- Beyond affecting occupancy rates, effect of business cycle is reflected on energy consumption (Henderson et al., 2011). May reflect the lower use-intensity of space (for instance, corporations having reduced presence in the space they occupy)

Temperature response estimations

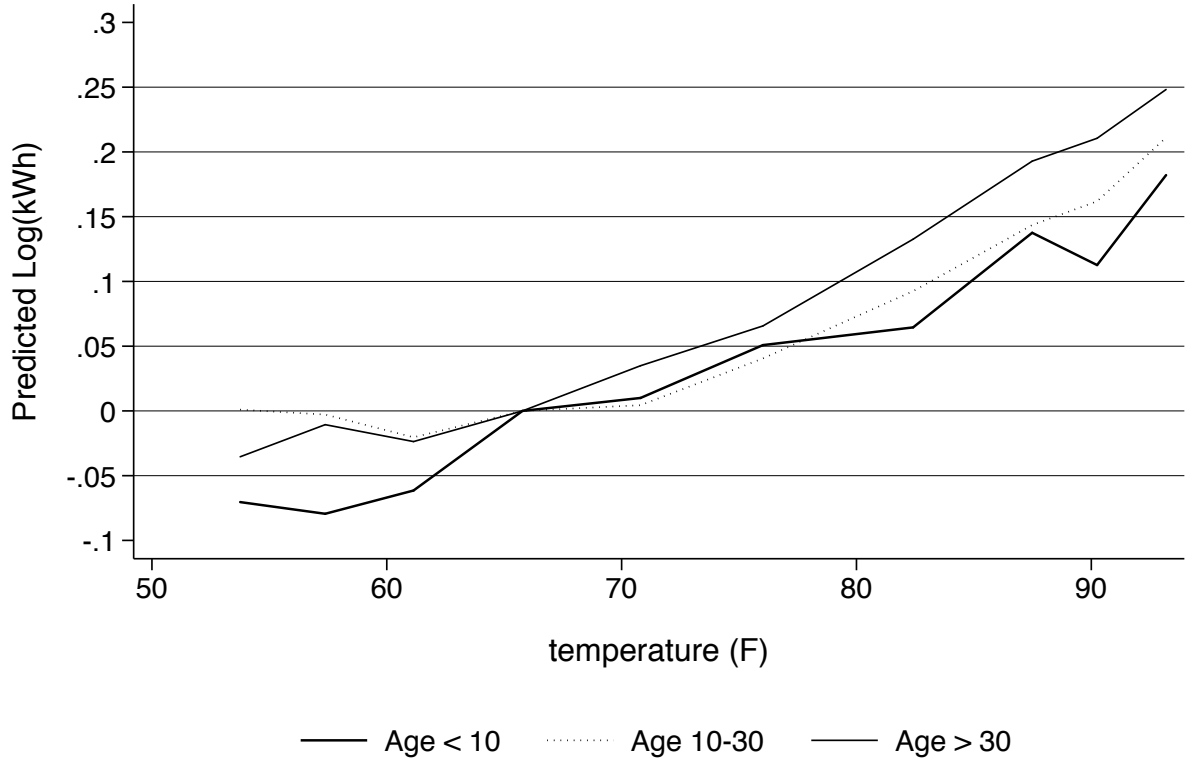
Interaction of temperature with age, quality, and contracts

Temperature Bin	Temperature	Occupancy	(Age 10-30)	(Age>30)	Class B	Class C	Triple Net	Modified Gross	Full Service
1st	-0.035	-0.045**	0.072***	0.036**	0.047***	0.072***	0.003	0.021	-0.035**
	[0.026]	[0.021]	[0.015]	[0.016]	[0.013]	[0.012]	[0.017]	[0.020]	[0.015]
2nd	0.059**	-0.157***	0.072***	0.062***	0.051***	0.056***	-0.045***	-0.025	-0.050***
	[0.026]	[0.021]	[0.016]	[0.016]	[0.013]	[0.012]	[0.017]	[0.020]	[0.015]
3rd	-0.030	-0.042**	0.040***	0.039**	0.014	0.023*	0.012	0.034*	-0.017
	[0.025]	[0.021]	[0.016]	[0.016]	[0.013]	[0.012]	[0.017]	[0.020]	[0.015]
5th	0.088***	-0.080***	-0.010	0.019	-0.028**	-0.035***	-0.052***	-0.069***	0.024
	[0.025]	[0.021]	[0.016]	[0.016]	[0.013]	[0.012]	[0.017]	[0.020]	[0.015]
6th	0.040	0.025	-0.013	0.010	-0.039***	-0.037***	-0.029*	-0.044**	0.029**
	[0.025]	[0.021]	[0.015]	[0.016]	[0.013]	[0.012]	[0.017]	[0.020]	[0.014]
7th	0.037	0.040*	0.026*	0.066***	-0.041***	-0.033***	-0.013	-0.030	0.034**
	[0.025]	[0.021]	[0.015]	[0.016]	[0.013]	[0.012]	[0.017]	[0.020]	[0.015]
8th	0.094***	0.062***	0.004	0.052***	-0.011	0.010	-0.026	-0.050**	0.042***
	[0.027]	[0.022]	[0.016]	[0.016]	[0.013]	[0.012]	[0.018]	[0.020]	[0.015]
9th	0.044	0.096***	0.045***	0.093***	-0.012	0.021*	-0.028	0.005	0.041***
	[0.027]	[0.021]	[0.016]	[0.017]	[0.013]	[0.012]	[0.018]	[0.021]	[0.015]
10th	0.102***	0.110***	0.027*	0.063***	-0.029**	0.008	-0.026	0.003	0.041***
	[0.026]	[0.021]	[0.015]	[0.016]	[0.013]	[0.012]	[0.017]	[0.020]	[0.014]
F test	6.25	29.47	8.03	6.12	12.08	19.53	2.77	5.30	10.38
(p-value)	0.000	0.000	0.002	0.000	0.000	0.000	0.003	0.000	0.000
Observations	299,726								
R-squared (within)	0.134								
Number of Buildings	2,976								

- In 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

Temperature response estimations – age

Recently constructed buildings less responsive to shocks



- More recently constructed buildings react less strongly to changes in temperature – inconsistent with “behavioral hypothesis” on rebound effect.

Conclusions and implications

Energy consumption commercial RE bound to increase

- Durable building stock is a major consumer electricity, and this is bound to increase. Between 2005 and 2030:
  - Residential electricity use is predicted to increase with **39 percent**
  - Industrial electricity use is predicted to increase with **17 percent**
  - Commercial electricity use is predicted to increase with **63 percent** (!!)
- We document an inverse relation between building vintage (and quality) and electricity consumption intensity
  - Contrasts with evidence on residential structures, so policymakers might be lulled…
  - Comparable to technological progress in automobiles (Knittel, 2012)
- Facing a marginal cost matters for energy consumption (comparable to evidence for residential sector)
- Presence of human capital seems to be effective in saving energy

Conclusions and implications

Future policies should focus more on commercial sector

- Some explanations for our results
  1. Building codes have been developed for commercial buildings (targeting 25 percent savings), but these mostly affect energy consumption for heating (Belzer et al., 2004);
  2. The composition of the fuel mix has shifted away from gas and heating oil (the “electrification” of society);
  3. Accelerated diffusion of personal computers, printers and other equipment may comprise a significant amount of the recent increase in electricity consumption (the “computerization” of society);
  4. The behavioral response of building tenants may lead to more intensive use of more efficient equipment as marginal price of “comfort” is lower

- Future policies should focus more on commercial sector
  - Mandatory disclosure of “in use” energy labels
  - Targeted subsidies or interventions using predictive modeling for energy “hogs”
  - “Nudges” for tenants