The Impact of Energy Efficient Equipment on Household Energy Use in Canada: Programmable Thermostats

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The Use and Usefulness of Programmable Thermostats as Inexpensive Household Energy Savings Devices in Canada

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Building Energy End-Use

CBEEDAC DATA AND ANALYSIS CENTRE

Motivation

- Canada’s “One-tonne challenge”:
  - Public program that challenges each Canadian to reduce their annual GHG emissions by 1 tonne
  - Average Canadian contributes 5 tonnes of GHG emissions per year
  - Together, individual Canadians contribute >25% of Canada’s GHG emissions

www.climatechange.gc.ca/onetonne/english/about.asp

Motivation

- Personal GHG emissions in Canada:

Road Transportation	49.9%
Space heating and cooling	29%
Water heating	11.1%
Appliances	7.5%
Lighting	2.4%

  - 61% of per-capita residential end-use energy consumption is for space heating

Motivation

- Largest potential gains in residential energy use are in space heating
- Many energy savings measures are expensive:
  - Double or triple pane windows
  - Increased insulation (attic or wall)
  - Higher efficiency furnaces
- But some are inexpensive:
  - Weatherstripping or caulking windows
  - Using a Programmable thermostat

Programmable Thermostats (PT)

- Temperature-sensitive switch to control a furnace (or a/c) by adjusting the temperature setting to preset levels for prescribed periods:
  - Working hours (house unoccupied)
  - Wake/evening
  - Night (temp less of a comfort concern)
- To qualify for Energy Star rating:
  - ≥ 2 different program periods (weekday, weekend)
  - ≥ 4 possible settings (wake, day, evening, sleep)

PT Cost Effectiveness

- Claims of large potential savings:
  - NRCan: 2% of home heating costs for each 1°C (1.8°F) that the thermostat is set lower
  - US DOE: 10% of heating and cooling costs if the thermostat is turned back 10%-15% (e.g., from 20°C to 17°C-18°C) for 8 hours.

PT Cost Effectiveness

- Relatively low cost (Energy Star PT):
  - US DOE (Energy Saver website):
    - Incremental cost: $107
    - Annual savings: $29
    - Payback period: 3.7 years
    - After-tax annual rate of return: 30%**

**4th best of 10 energy efficiency measures, where:

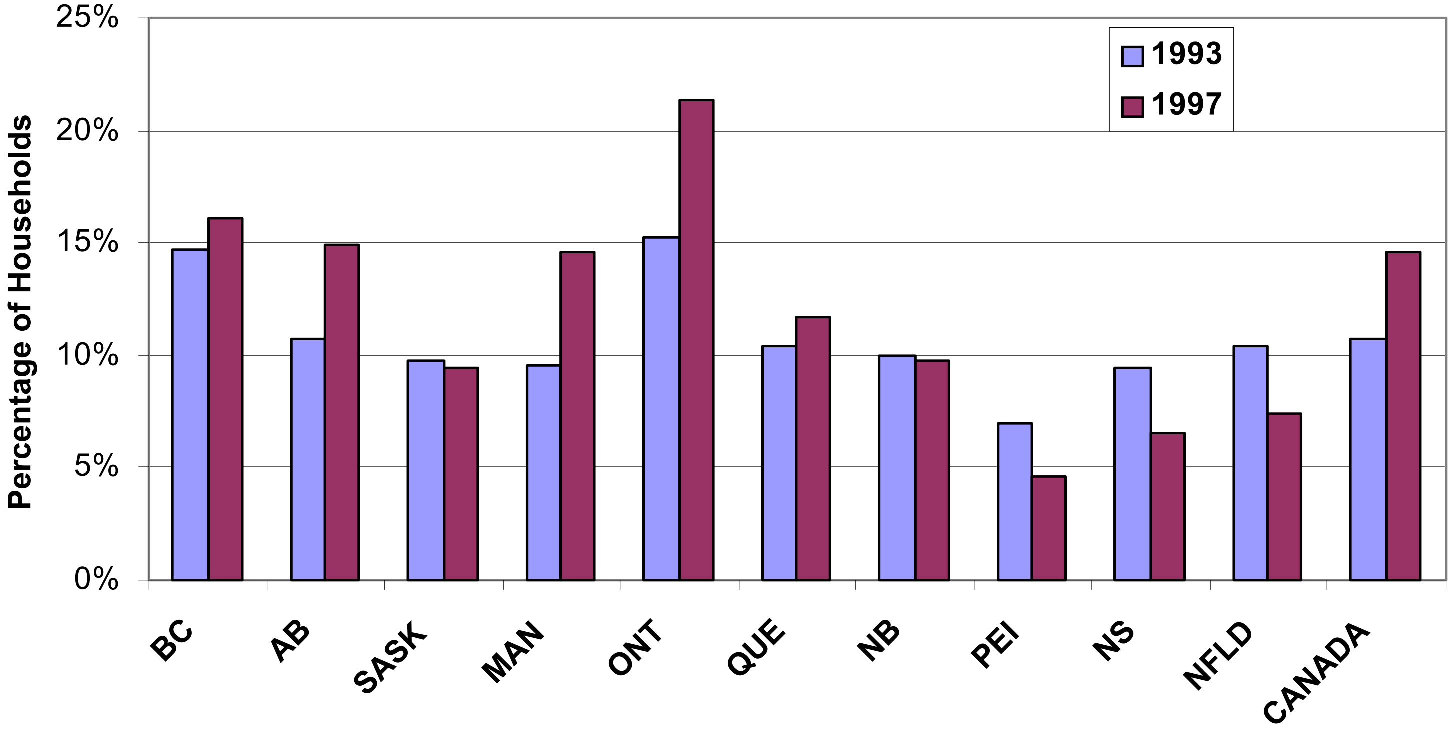
(i) fluorescent lamps and fixtures (41%)

(ii) duct sealing (41%)

(iii) energy star clothes washer (37%)

Cost effective but….

- Not widely used in Canada:



Programmable Thermostat Issues

- Why not widely used in Canada?
  - Too hard to configure/reconfigure?
  - Desire not to lower daytime temp?
  - Inconvenient/frequent override?
  - Claimed energy savings not actually realized?

Focus of Current Analysis

- Determine who uses a PT in Canada
- Determine whether there is evidence that use of a PT results in energy savings, and attempt to quantify the extent of any such savings
- Account for endogeneity of decision to have/use a PT when assessing savings
- Account for differences between “having” a PT and “appropriately using” a PT

SHEU97 Household Survey Data

- Canadian Survey of Household Energy Use, 1997 (2003 not yet available)
- 4563 households from across Canada
- Energy use, house characteristics, demographic and socio-economic information (not energy prices)
- Does household equipment include a PT?
- Not asked if automatic features of PT were actually used
- Energy use imputed in some cases

Previous Analysis of Thermostats

- Nelson (1973):
  - Computer simulation models showed a nighttime temperature setback could reduce heating fuel consumption by 9% on average (15% in milder climates)
- Good Housekeeping Institute [Quentzel, 1976]:
  - one single dwelling, 4-person household, 74-75 heating season ► 8°F setback yields 10% fuel savings

Previous Analysis of Thermostats

- Quentzel (1976):
  - recommended using a PT because occupant may forget to manually adjust settings, and may find it inconvenient to do so at (e.g.) 6AM
- Nelson and MacArthur (1978):
  - computer simulation shows greater savings with longer/larger setbacks or dual setbacks (lower temp during day and at night)

Previous Analysis of Programmable Thermostats

Potential energy savings
≠ *Actual* energy savings

- Cross and Judd (1997):
  - should compare PT to a manual thermostat rather than to no thermostat
- Nevius and Pigg (1999):
  - sample of 299 owner-occupied, single-family dwellings in Wisconsin in 1999 (33% have a PT and 83% of these claim to use its automatic features)

Previous Analysis of Programmable Thermostats

- Nevius and Pigg (continued):
  - little difference between average temperatures in different daily time periods with or without PT
  - High correlation between "conservation orientation" and reported thermostat setpoint

Conjectures of Nevius & Pigg (1999)

- *Attitudes* toward energy consumption and efficiency determine thermostat-setting behaviour and hence heating energy consumption

– If household is not "conservation-oriented", then PT unlikely to yield lower thermostat setting or significant energy savings

– households that are more focused on energy conservation are more likely to have and to use a PT

Empirical Implication of Nevius & Pigg

- There is an endogeneity issue when examining effect of PT on energy demand:

  -If simply include "presence of a PT" as a dummy variable in an energy demand equation, it is likely that energy savings attributable to a PT will be overstated

    - if it is energy-conscious households that are more likely to have a PT and to use less energy, it will appear that the PT results in reduced energy use, when in fact it is due to the household's general approach to energy efficiency and use.

Solution

- Estimate an energy demand model with "presence of PT" included as an explanatory variable, but estimate it as a *TREATMENT EFFECT* model
- First stage: Probit estimation of decision to have a PT
- Second stage: Estimate energy demand equation (all observations) with correction term (or using instrumental variable) that involves parameters from the first stage

Houses in Canada with a PT

Type	% of sample	% with a PT	Year built	% with a PT
Single detached	85.4%	15.1%	Pre 1921	11.3%
Row or terrace	6.5%	12.8%	1921-1940	12.4%
Double	4.8%	10.5%	1941-1955	12.2%
Mobile homes	3.3%	9.4%	1956-1965	12.7%
Natural gas	40.8%	19.9%	1966-1977	14.5%
Electricity	24.2%	10.0%	1978-1982	12.7%
Oil	15.5%	11.7%	1983-1989	17.3%
Wood	8.3%	5.8%	1990-1995	23.6%
Forced Air furnace	62.9%	17.7%	1996-1997	13.2%
Boiler-type furnace	6.3%	11.5%		
Heating stoves	8.0%	6.1%	Have AC (16.5%)	30.3%
Electric radiant heat	0.8%	16.7%	No AC	11.2%
Electric baseboards	18.7%	7.7%		

Houses with/without a PT

Variable	With a PT	No PT
Average heated area	1573.8 sq ft	1320.1 sq ft
Average household size	3.02	2.82
Average age of main heating equipment	12.7 years	14.7 years
% in 1997 making home improvements:		
Wall insulation	3.6%	3.0%
Attic insulation	4.7%	3.7%
Window replacement	12.3%	9.7%
Weather stripping/caulk	15.8%	13.0%
Average natural gas consumption (GJ)	122.67	121.02
Average electricity consumption (kWh)	12400.5	13091.73

Households in Canada with a PT

Annual income	% with a PT
< $20,000	7.2%
$20,000 - < $40,000	11.5%
$40,000 - < $60,000	13.4%
$60,000 - < $80,000	19.7%
$80,000+	27.6%
Education level	**% with a PT**
Not a HS graduate	8.4-10.1%
HS graduate	15%
Trade/Univ certificate	10.7-12.4%
Some PS/CC	16.5-17.4%
Bachelor or grad degree	23.3-23.4%

“Having” versus “Using” a PT

- Are households that have a PT (survey question) actually using its automatic features?
  - If not, then to the extent that using these features of a PT lower energy consumption, would not expect to be able to attribute much energy savings to having a PT.
  - Preferable to be able to distinguish “having” and “using” a PT.

PT Use and Thermostat Settings

- Average temperatures (°C)

	Daytime (6AM-4PM)	Evening (4PM-11PM)	Night (11PM-6AM)
With a PT	19.76	20.60	18.73
No PT	20.03	20.42	19.02

- Possible energy savings with a PT
- But this masks many cases where settings do not change between periods

PT Use and Thermostat Settings

Temperature Settings	Average Internal Temperature (°C)							
	Houses with Specified Settings					Remaining Houses		
	% HH	% SH	Day	Eve	Night	Day	Eve	Night
D=E (PT)	55.2%	69%	20.67	20.67	19.22	18.64	20.53	18.12
D=E (no PT)	71.0%	68%	20.44	20.44	19.34	19.04	20.38	18.25
E=N (PT)	34.6%	63%	20.38	20.21	20.21	19.43	20.81	17.94
E=N (no PT)	48.6%	61%	20.16	20.15	20.15	19.91	20.68	17.96
N=D (PT)	49.0%	44%	19.35	20.64	19.35	20.15	20.57	18.12
N=D (no PT)	51.9%	56%	19.79	20.29	19.79	20.30	20.56	18.19
D=E=N (PT)	27.1%	64%	20.56	20.56	20.56	19.46	20.62	18.05
D=E=N (no PT)	41.7%	62%	20.25	20.25	20.25	19.88	20.55	18.14

So “having” a PT $\neq$ “using” a PT

- Focus on two groups:
  - “have” a PT
    - respond “yes” to question about having a PT
  - “use” a PT
    - Respond ‘Yes” to having a PT
    - Do NOT set d=e=n temperatures
- Could also consider other groups (e.g., d=e temperatures) as only “partially” using a PT

Probit model of PT decision

Main variables:

- AC, HOME, HAREA, HAGE, HDD, AGE
- Renovations in 1997 (RENOV)
  - Attic, Wall, Window, Caulk, Heat area
- Heating system: FAF, BOIL, STOVE
- Main heating fuel: NGAS, ELEC
- Region: QUE, ONT, PRAIR, BC
- Education: HIED, LOED
- Income: INC2, INC3, INC4, INC5
- Demog: HHSIZE, BABY, TODD, KIDS

Variable	Households with a PT (ln L=-1563.3)		Households “using” a PT (ln L = -1283.6)	
	Coefficient (std error)	Marginal Effect	Coefficient (std error)	Marginal Effect
AC	0.4271** (0.0683)	0.0641	0.2389** (0.0745)	0.0212
HOME	-0.1705** (0.0532)	-0.0211	-0.2528** (0.0580)	-0.0228
HAREA	0.00017** (0.00004)	0.00003	0.0001** (0.00005)	0.00002
HAGE	-0.0069** (0.0027)	-0.0014	-0.0054† (0.0029)	-0.0009
HDD	-0.00005 (0.00004)	-0.00001	-0.00007 (0.00004)	-0.00001
RENOV	0.0934 (0.0576)	0.0109	0.0657 (0.0629)	0.0050
FAF	0.3838** (0.0748)	0.0302	0.2417* (0.1025)	0.0138
BOIL	0.2735* (0.1220)	0.0366		
STOVE			-0.2828† (0.1590)	-0.0155
ELEC			-0.3153** (0.1095)	-0.0168
QUE	0.4014** (0.0983)	0.0591	0.3715** (0.1110)	0.0372
ONT	0.2300* (0.0930)	0.0298	0.1418 (0.1027)	0.0115
PRAIR	0.1182 (0.1017)	0.0140	0.0696 (0.1119)	0.0053
BC	0.2094† (0.1160)	0.0267	0.2346† (0.1245)	0.0208
HIED	0.1569* (0.0706)	0.0192	0.1778* (0.0749)	0.0150
BABY	0.2705** (0.0865)	0.0361	0.2867** (0.0971)	0.0267
HHSIZE			-0.0372† (0.0224)	-0.0059
INC2	0.1765* (0.0878)	0.0219	0.2983** (0.1038)	0.0280
INC3	0.1467 (0.0929)	0.0178	0.3053** (0.1103)	0.0288
INC4	0.3261** (0.0990)	0.0454	0.5126** (0.1173)	0.0580
INC5	0.4208** (0.1045)	0.0628	0.5936** (0.1230)	0.0718
CONSTANT	-1.7100** (0.2349)		-1.5492** (0.2668)	

Energy Consumption Model

- Alternatively include “have” and “use” PT as an explanatory variable
- Supplement survey data with price of natural gas, electricity
  - Currently by province; expand to CMA
- Only use observations with real consumption data
- Estimate separately for natural gas, electricity consumption

Energy Consumption Model

- Initially treat "having" or "using" a PT as exogenous, and compare later to treatment effect approach
- Consider alternative functional forms:
  - Dependent variable: C, lnC, Exp, lnEXP
  - Continuous explanatory variables: HAGE, HHSIZE, HAREA, HDD, STOREYS, EPRICE, GPRICE (linear or natural logarithms)
- Additional variables:
  - #weeks away, #weekends away
  - type of dwelling (double, row/terrace, mobile)

Natural Gas Demand Equation Estimates

	Dependent variable = Ln (Q-natgas) (n=1340)	
	Coefficient (std error)	Coefficient (std error)
PT (have)	-.0535* (.0214)	
PT (use)		-.0605** (.0219)
L-HAREA	.3635** (.0316)	.3613** (.0313)
L-HAGE	.0468** (.0091)	.0473** (.0090)
L-HDD	.3560** (.0663)	.3550** (.0665)
L-STORIES	.0433** (.0130)	.0427** (.0129)
FAF	.5382** (.1122)	.5626** (.0926)
BOIL	.7777** (.1257)	.8047** (.1079)
DOUBLE	-.0880† (.0483)	-.0892† (.0486)
ROW/TERR	-.2642** (.0339)	-.2626** (.0338)
MOBILE	-.1984** (.0610)	-.1977** (.0610)
WKSAWAY	-.0035† (.0021)	-.0035† (.0021)
WKENDSAWAY	-.0022* (.0009)	-.0021* (.0009)
ATTIC	.0124 (.0413)	.0127 (.0413)
WALL	-.0006 (.0491)	-.0040 (.0495)
HAREAINC	.1636** (.0614)	.1609** (.0578)
WINDOW	-.0506 (.0322)	-.0508 (.0324)
CAULK	.0227 (.0209)	.0227 (.0210)

Natural Gas Demand Equation Estimates (continued)

	Dependent variable = Ln (Q-natgas) (n=1340)	
	Coefficient (std error)	Coefficient (std error)
L-ELECPR	.3224 (.3206)	.3407 (.3204)
L-NGASPR	-.1302 (.2880)	-.1216 (.2879)
BABY	-.0332 (.0268)	-.03400 (.0267)
TODD	.0415 (.0260)	.0413 (.0261)
KIDS	.0182 (.0178)	.0184 (.0178)
HIED	-.0453† (.0274)	-.0458† (.0273)
HOME	-.0261 (.0181)	-.0280 (.0179)
INC2	-.0165 (.0259)	-.0155 (.0258)
INC3	-.0746* (.0324)	-.0732* (.0324)
INC4	-.0333 (.0305)	-.0315 (.0305)
INC5	.0026 (.0333)	.0041 (.0334)
BC	.0479 (.1283)	.0582 (.1265)
PRAIR	.0094 (.1490)	.0174 (.1474)
ONT	-.1109 (.0806)	-.1090 (.0775)
Constant	-2.1807 (1.6534)	-2.2620 (1.6527)
R-squared	.3189	.3190

Summary of results

- Estimated standard errors are heteroskedasticity corrected
- Regardless of specification, both PT variables significant (“use PT” more significant than “have PT”)
  - ► PT saves energy
- Same variables significant using either PT explanatory variable

PT as a Treatment Effect

- Allow for endogeneity of PT
- Model PT decision (probit in smaller sample), then in energy (ngas) demand equation that includes PT use either:

  (i) predicted values as instrument for PT,

or

  (ii) sample selectivity correction (all obs)

In either case, and with either PT variable, PT is not significant!

Summary and Conclusions

- PT not widely adopted in Canada, despite low cost and apparent relatively large benefits
- Estimated a Probit model of decision to have a PT, or to use a PT (potentially different decisions).
- Probit results generally consistent with expectations

Summary and Conclusions

- Include PT in energy (natural gas) demand equation
- PT coefficient significant and negative.
- But when take account of potential endogeneity of decision to have/use a PT, this variable is no longer significant.

Summary and Conclusions

- Appears that despite "engineering-type" evidence, having/using a PT does not reduce energy use once take account of endogeneity

►Supports Nevius and Pigg conjectures:

i.e., it is *Attitudes* toward energy consumption and efficiency that determine thermostat-setting behaviour and hence heating energy consumption

Summary and Conclusions

- Households that are more focused on energy conservation are more likely to have and to use a PT
- If household is not “conservation-oriented”, then PT unlikely to yield significant energy savings

► important implications for public policy measures designed to reduce energy consumption by inducing adoption of energy-savings devices
(need to explore this issue further)

Thermostat Humour…..

A customer was bothering the waiter in a restaurant. First, he asked that the air conditioning be turned up because he was too hot, then he asked it be turned down because he was too cold, and so on for about half an hour.

Surprisingly, the waiter was very patient; he walked back and forth and never once became angry.

Finally, a second customer asked him why he didn't throw out the pest.

"Oh, I really don't mind," said the waiter with a smile. "We don't even have an air conditioner."