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The Impact of Sub-Metering on Condominium Electricity Demand

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Abstract:

Growing concern about the environmental effects of electricity generation is renewing demands for electricity conservation and efficient usage. With a substantial fraction of the population insulated from energy price signals in bulk-metered apartment and condominium buildings, some jurisdictions are considering mandatory metering of individual suites. This study analyses data from a Toronto condominium building to assess the impacts of suite (or sub-) metering. We estimate the aggregate reduction in electricity usage arising from sub-metering to be about 20%. We analyze large variations across units in electricity consumption after sub-metering finding that unit characteristics explain much but not all of this variation. We perform both private and public cost-benefit analyses of sub-metering and find that the social net benefits depend strongly on the value assigned to externalities from generation and that net social benefits may often be positive when private benefits to the residents are negative.

1. Introduction

Twenty-six percent of Ontario-residents live in multi-unit buildings[1] and between 75 to 90 percent of these buildings use bulk metering in which a single meter measures all electricity use.[2] Together, this implies that approximately one-fifth of Ontario's residential electricity costs are determined as shares of total building usage. Growing demands for energy conservation have increased interest in the sub-metering of multiple-unit residential apartment and condominium buildings. However, the costs and benefits depend on many factors from the design of the building to the fixed costs of serving individual customers. In addition, one must also consider the degree of within-building cross-subsidization prior to sub-metering since this will determine what fraction of residents will pay more after sub-metering despite conservation. Proposals to encourage sub-metering have met with stiff resistance from tenants' organizations[3]. Empirical analysis is needed to determine what conditions generate benefits that exceed costs for the residents or for society.

This study examines the effect of sub-metering in a residential condominium building in Toronto, Ontario, on aggregate electricity consumption and on the cost of electricity to individual unit owners. We analyze almost a decade of monthly temperature, electricity consumption and expenditure data to estimate a model that can identify the reduction in electricity consumption caused by installing meters on individual condominium units. We also study the effect of unit characteristics and location on unit electricity consumption utilizing unusually detailed data on the units. We draw conclusions regarding electricity savings, cost savings, and the private and social costs and benefits from sub-metering this building and the distribution of those costs and benefits among unit owners. We offer some projections as to the likely results in other types of buildings.

2. Previous Literature

Researchers have studied the price elasticity of residential electricity demand for decades. The Electric Power Research Institute recently reviewed nine of the most robust recent studies. The mean short-run residential elasticity of demand is -0.30, with individual estimates ranging from -

[1] Statistics Canada, Income Statistics Division, Cansim, table 203-0019 and Catalogue no. 62F0026MIE.
[2] Federation of Rental Housing Providers of Ontario testimony and Stratacon, Inc, testimony in Ontario Standing Committee (2006); Toronto, 2008, p. 2.
[3] In Ontario, see, *e.g.*, exhibits submitted for the Bill-21 hearings of the Standing Committee on Justice in 2005 regarding amendments to the Energy Conservation Leadership Act, 2005. Concerns in New York State are summarized in a Public Utility Law Project website at: http://www.pulp.tc/html/residential_submetering.html .

0.20 to -0.60. The mean long-run elasticity of demand is -0.90 with a range from -0.7 to -1.4 (EPRI, 2008, p. 20). The elasticities depend on conditions. One study reported that summer elasticity was -0.47 while winter elasticity was -0.27 (Archibald, Finifter and Moody, 1982, p. 177). A California study concluded that households without electric heat or air conditioning had low elasticities (-0.08) while households with air conditioning displayed elasticities of -0.64 and households with air conditioning and electric heat had elasticities of -1.02 (Reiss and White, 2005, p. 868). In addition, price-responsiveness seems to rise with income.

These studies examine small and large price changes but they do not examine prices of zero. Yet for residents of a bulk-metered apartment or condominium building with tens or hundreds of apartments who share the total building utility cost the price of consuming a marginal kWh is essentially zero.

One of the few refereed studies of the effects of sub-metering is Munley, Taylor and Formby (1990). They study a garden apartment complex in Washington D.C. in which 44 apartments were sub-metered in August 1979 but only 22 units were charged explicitly for their own consumption. Each unit's electricity provided heating and cooling for the unit but domestic hot water was centrally provided. The consumption of all units was measured during the 12 months prior to sub-metering and five months afterward. The study units paid prices that varied monthly from 2.75 to 4.05 cents/kWh in September, 1978 US dollars. The authors estimated a consumption equation in which price, heating degree-days (HDD) and cooling degree-days (CDD) were the principal explanatory variables. The study reports a short-run elasticity of -0.42 (MTF, 1990, p. 188) and substantial net benefits from sub-metering when metering and billing costs are ignored.

Subsequent studies by consultants or government departments focus on the reduction in electricity consumption arising from sub-metering. NYSERDA (2001) reports on six buildings in New York City that were sub-metered in the 1980s and 1990s. Three residential buildings[4] were monitored for usage in 1986 and then sub-metered in the early and mid-1990s. Building electricity consumption dropped 12%, 19%, and 20% in 1990-91 and in the mid-1990s the reductions (compared to 1986) were little changed at 15%, 17% and 19%. The cost savings were said to be similar to the electricity reductions (NYSERDA, 2001, p. 17). Seventy-three percent of residents paid less after sub-metering than before because of their reduced consumption

[4] Two were co-op buildings, which are similar to condominiums. The status of the third is unclear.

(NYSERDA, 2001, Appendix 1, p. 2). Another set of three buildings that were sub-metered in 1993-94 and analyzed in 1995-96 showed reductions in consumption of 17%, 14%, and 10% with cost savings of the same magnitude (NYSERDA, 2001, p. 18). The price of electricity is not identified and the methodology is not described but the study appears to have corrected for temperature. Metering and billing costs are not mentioned.

Most relevant to Canada is the Oakville Pilot Study in which three condominium buildings were converted from bulk metering to tiered prices (the Ontario Regulated Price Plan) and then to time of use prices, all during 2006. A regression model using HDD, CDD and time as explanatory variables was used to estimate that the two buildings in which tiered prices were in place for at least 4 months experienced reductions in consumption of 18% and 25%. The data spanned about seven years but the post-sub-metering time was less than a year. In all cases, there was little reduction in common area consumption; the savings were concentrated in the occupied units. (Navigant, 2008). Companies offering sub-metering report reduced electricity consumption of 20%-30% mostly from behavioural changes. (Ontario Standing Committee, 2006, 13:20, 13:50, 15:30, 15:40; Stratacon, 2009). Young and Maruejols (2009) report that electricity consumption is much higher in apartments where the landlord pays the electricity bills than where the tenant pays.

These studies suggest that sub-metering should reduce electricity consumption by 15% to 25% but it is not clear whether savings will outweigh the increased metering and billing costs. We add to this previous research by collecting and utilizing additional data. We analyze six years of pre-sub-metering data and 19 months of post-sub-metering data. The New York studies relied on one year of pre-sub-metering data and two years of post-sub-metering, while the Oakville pilot used only 2, 4 and 10 months of tiered prices post-sub-metering in the three buildings. Most important, we carefully compare total costs before and after sub-metering, including all metering and billing costs. We also estimate the welfare impacts associated with eliminating the cross-subsidization inherent in bulk metering.

3. Data

Our study building is a luxury condominium building in Toronto, Ontario, built in the 1970's with 40 units on three levels, some of them occupying multiple floors. The building has large separately wired units, with electric heat, hot water, laundry appliances, stove, and air conditioning in each unit. This is the ideal building for maximizing the effect of sub-metering. In

Table 1: Study Building and Unit Characteristics

	Mean	Standard Deviation
Building Characteristics, 2001-2009		*Across Months*
Monthly Electricity Usage, whole building (kWh)	124,288	61,887
Monthly Common-Area Electricity Usage	26,715	21,694
Unit Characteristics		*Across Units*
Heated Floor Space (square feet)	1896	397
Exterior Wall Exposure (feet)	78	42
Average Monthly Unit Electricity Usage, Post-Metering (kWh)		
Winter (Nov.-Apr.)	3596	1088
Summer (May-Oct.)	1513	581
Average Monthly Unit Cost, Post-Metering ($)		
Winter (Nov.-Apr.)	262	99
Summer (May-Oct.)	132	55

this building the owners debated the merits of sub-metering before it was contracted so they were aware of the change before the start date of April 1, 2008. They received advice on energy conservation.

Aggregate monthly electricity consumption data for the entire building are available in three blocks, from May 1995 to April 1998, from January 2001 to December 2003 and from January 2005 through November 2009. Reading errors and estimated readings prior to sub-metering cause some monthly consumption figures to be incorrect, sometimes seriously so. We correct these errors with a statistical smoothing technique, the details of which are presented in Appendix A. We have monthly unit consumption and cost data starting April, 2008 for all but two units which did not consent to release their data. HDD and CDD data are available from Environment Canada. A summary of various descriptive statistics is displayed in Table 1. Average monthly consumption during the winter is more than twice that in the summer due to resistance electric heating. Theory suggests that electricity use for heating and cooling should be closely related to HDD and CDD respectively; lighting use should be greater in winter while hot water and appliance use will depend on lifestyles.

4. Aggregate Analysis of Electricity Consumption

To determine the impact of sub-metering on aggregate building consumption we estimate the following equation:

$$(1) \qquad Log(Usage_t) = \beta_0 + \beta_1 SM_t + \beta_2 HDD_t + \beta_3 CDD_t + \sum_{m=2}^{12} \alpha_m + \varepsilon_t$$

where HDD_t and CDD_t are the heating and cooling degree days in the month as reported by Environment Canada, α_m are monthly fixed effects, and SM_t is the variable of interest that is 0 before April 1, 2008 and 1 afterwards. Results for various combinations of these variables are shown in Table 2. Our preferred specification is (4), with an R^2 of 0.97 suggesting that time-of-year and climatic variation are the predominant predictors of aggregate electricity consumption. Specifically, ten more CDDs or HDDs in a typical month increase electricity consumption by 1%. Most importantly, the first line shows that sub-metering reduced consumption by 20%.

Table 2: Aggregate Impact of Sub-Metering

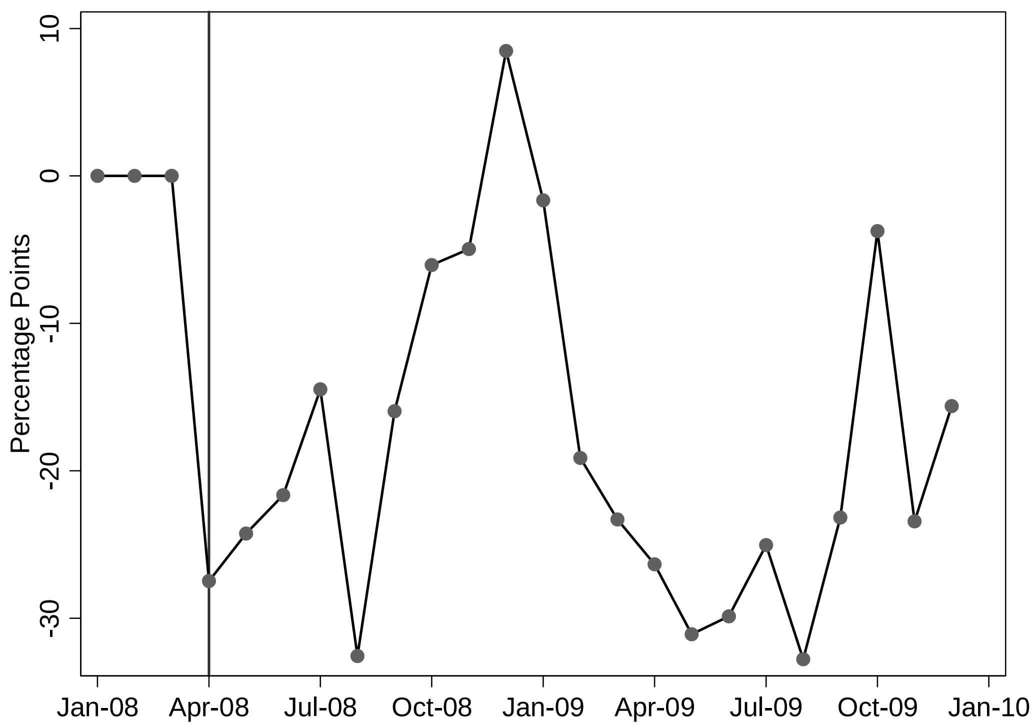
	Dependent Variable: Log(Electricity Consumption)			
Variable	(1)	(2)	(3)	(4)
Sub-metering Dummy	-0.319***	-0.207***	-0.203***	-0.204***
	[0.116]	[0.026]	[0.029]	[0.022]
Heating Degree Days			0.002***	0.001***
			[0.000]	[0.000]
Cooling Degree Days			0.002***	0.001***
			[0.000]	[0.000]
Constant	11.682***	12.393***	10.945***	11.508***
	[0.054]	[0.037]	[0.033]	[0.124]
Month Controls	No	Yes	No	Yes
Observations	96	96	96	96
R^2	0.065	0.954	0.943	0.973

*** significant at the 1% level. Coverage years: 2001-2003, 2005-2009. Standard errors in brackets.

4.1 Less conservation in winter

To examine the timing of the response to sub-metering we use equation 1 to predict post-sub-metering consumption and we plot the deviation between actual and predicted consumption in Figure 1. Conservation is substantial in the summer, exceeding 30% in August in both years while November 2008 through January 2009 show little conservation. If we divide the year into two seasons, with summer running from May through October, the savings average 11% in the winter and 21% in the summer.[5] This is consistent with Archibald *et al*. (1982) who report summer elasticities almost twice as great as winter elasticity. Looking across the months we find that conservation is greatest in spring and summer, modest in fall, and least in winter. This is consistent with the hypothesis that much of the conservation was achieved by less intensive use of electric appliances and lights. The modest mid-winter conservation may reflect the reluctance of these residents to sacrifice much comfort in the middle of the Canadian winter.

Figure 1 Monthly Deviation of Post-Sub-metering Aggregate Consumption from Predicted Consumption (%)



Prediction based on Equation 1 estimated over 2001-2003, 2003-November 2009 and actual temperatures after March 2008.

[5] The absolute savings in summer are 17,134 kW/h and in winter they are 22,225 kW/h so the higher summer percentage is only partly the result of a lower base.

5. *Physical determinants of unit consumption post-sub-metering*

The units in this building are heterogeneous and residents were eager to know if their electricity bills were 'fair' although that term was not well defined. We developed a model to explain the consumption of individual units as a function of physical characteristics including heated floor space, exterior wall exposure, balcony type and floor location. We performed a statistical analysis on the post-sub-metering monthly consumption data for the individual units that provided access to their data. Because the aggregate analysis indicated substantial differences in conservation between summer (May-October) and winter (November-April) we analysed the two seasons separately and of course we included HDD or CDD in the equations. The post-metering unit cross section specification is given by

(2) $$Log(Usage_{it}) = \beta_0 + \beta_1 \boldsymbol{X}_{it} + \beta_2 HDD_t + \beta_3 CDD_t + \sum_{m=2}^{12} \alpha_m + \varepsilon_{it}$$

where $\mathbf{X}_i$ is a vector of individual unit characteristics: square footage; exterior wall exposure length; balcony-type (enclosed, or fully open); building floor level; direction of exposure (North, South, etc); vacancy (vacations, for instance); and tenancy status (owner or tenant occupied). CDD_t is included only during the summer months. The results are presented in Table 3.

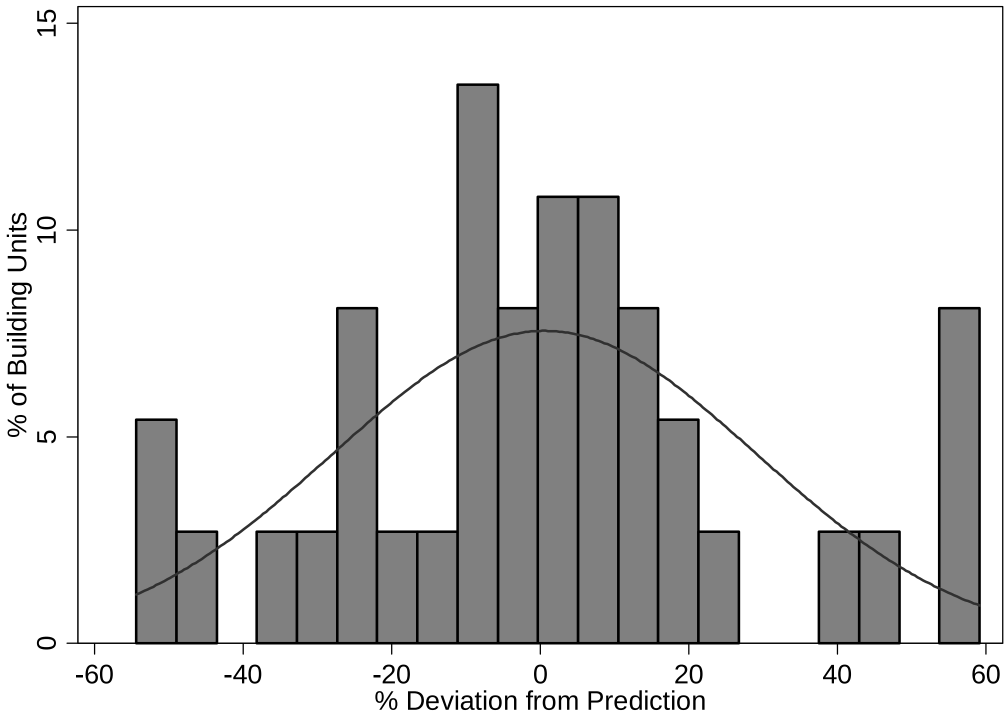
We interpret these results as follows. Our unit characteristics explain almost ¾ of winter consumption but less than 40% of summer consumption. Heating degree days are a significant determinant of electricity consumption in winter and cooling degree-days have some effect on electricity consumption in summer. Units with 10% greater exterior wall exposure use approximately 61 kW/h more electricity per month in the winter but exterior exposure has no significant effect in the summer. Units with 10% greater interior heated area use approximately 139 kW/h more electricity per month in the winter and approximately 84 kWh more in the summer. The top level units use 222 kWh/month (13%) less electricity in the summer than the ground level units after adjusting for floor space and exterior area. A vacant unit uses 887 kWh/month less electricity in winter than an occupied unit, a saving of 34%. The summer saving from vacancy is nearly 600 kWh/month, almost 40% of monthly summer usage.

Table 3: Cross Sectional Consumption Patterns, by Season

	Dependent Variable: Log(Electricity Consumption)	
Variable	**Winter**	**Summer**
Log(Exterior Exposure)	613.1***	-229.9**
	[175.6]	[101.8]
Log(Heated Area)	1387.1***	844.4***
	[438.8]	[249.4]
Middle Floor (relative to 1st)	82.1	133.3
	[157.8]	[89.88]
Top Floor (relative to 1st)	48.34	-222.3***
	[125.2]	[71.91]
Heating Degree Days	7.729***	3.517
	[1.625]	[2.897]
Cooling Degree Days		3.770**
		[1.602]
Vacancy	-887.3***	-596.1***
	[143.7]	[99.64]
Tenancy	35.46	-90.7
	[192.9]	[107.0]
Single Occupancy	-419.8***	-257.8***
	[112.4]	[64.34]
Constant	-15158.6***	-4490.6**
	[3354.7]	[1924.6]
Balcony-Type Controls	Yes	Yes
Month Controls	Yes	Yes
Observations	296	444
R^2	0.743	0.42

*** statistically significant at the 1% confidence level; ** = 5%. Coverage: April 2008-November 2009. Standard errors in brackets.

Figure 2: Deviations of Unit Consumption from Prediction



Prediction based on Equation 2 using post-sub-metering unit consumption data.

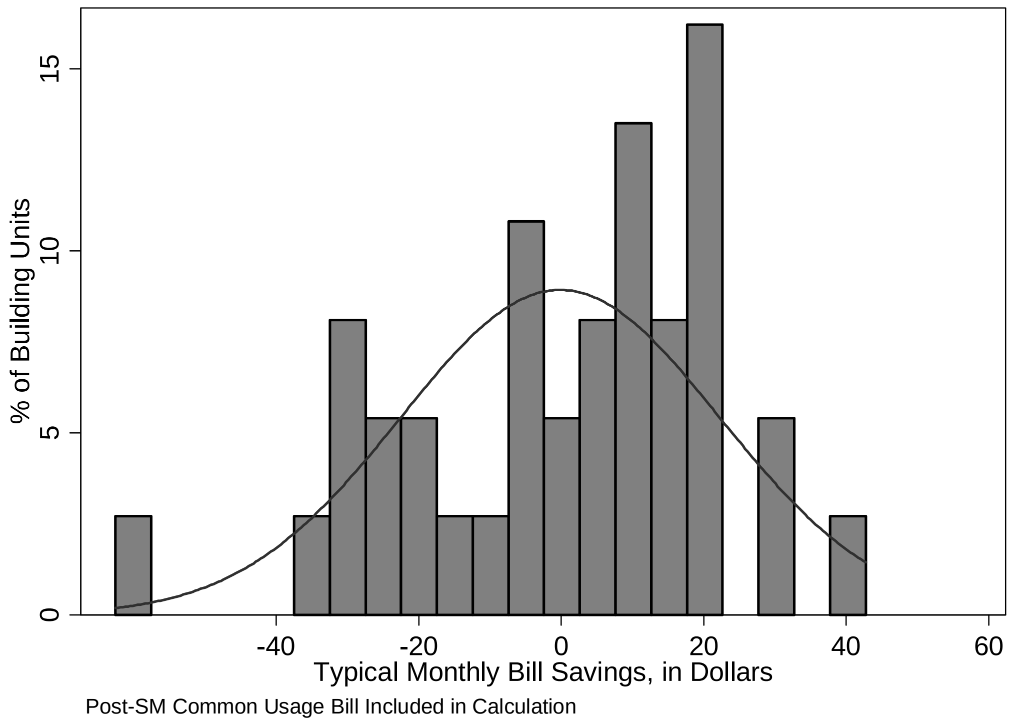
We explore the 'lifestyle' variation further by using Equation 2 to predict the average monthly consumption of each unit post-sub-metering and comparing this with actual average monthly consumption. Figure 2 shows the density distribution of these deviations. Most units consume electricity within +/- 30% of the predicted amount. Three units, however, use 50% to 60% less electricity than our model predicts. Five units use over 40% more electricity than our model predicts. Either there are substantial lifestyle differences among these unit owners or there are features of their units that impact electricity consumption in a major way that is not captured in our unit characteristics.

6. Customer Perception of the Financial Effects of Sub-metering

The introduction of sub-metering changed electricity costs for unit owners in three ways. First, the unit owner now pays for his or her actual electricity consumption rather than paying for a share of the total building consumption allocated by a formula based on floor area. Even if there were no behavioural changes some unit owners would pay more (less) than before because they used more (less) electricity than the share allocated to them by the formula. Second, with sub-metering unit owners could and did save money by reducing their electricity consumption. Third, sub-metering introduced new bill elements and calculations for unit owners. The owners pay the same price per kWh for electricity as the entire building paid previously. After sub-metering, however, *each* owner pays a delivery charge while previously there was a single delivery charge for the entire building. The fixed portion of the delivery charge adds $12.55 to the monthly cost for each unit owner. They also pay a price multiplied by the sum of their peak hourly demands (kW) for each day of the month. Previously the building paid a demand charge based on the building's peak hourly demand at any time during the month. In Section 7 we determine that delivery costs have increased substantially relative to the cost of the electricity commodity itself.

The owners instinctively compare their costs after sub-metering with the corresponding cost for recent years, without adjusting for weather or price changes. While this is not economically relevant it does predict how they will perceive the sub-metering project. A simple comparison of before-and-after costs measures whether the owners will be happy or unhappy with the change. The average annual cost of electricity for building for the three years prior to sub-metering was $142,443, excluding GST. The sum of the common and unit costs in the first 12 months post-sub-metering was $141,483, excluding GST. The simple savings are $960 or 0.67%, not enough to generate enthusiasm among the owners. We do not know how much electricity each individual unit consumed prior to sub-metering. However, we can compare the actual costs post-sub-metering with the amounts that unit owners paid for electricity through their condominium fees prior to sub-metering. We took the average annual electricity cost for the building in 2005-2007 and allocated it to individual units according to the condominium allocation formula. We added to the actual bill amounts from April 2008 through March 2009 the share of the common cost for the same period based on the allocation formula. Subtracting the post-sub-metering costs from the allocated pre-sub-metering cost compares the costs that owners actually experience. Figure 3 shows that about half of owners paid less than they paid in 2005 through March, 2008, despite the cold winter, a 3% increase in electricity price and the increased delivery charges. However, almost half of the owners paid more with sub-metering than they paid under the allocation formula and some are paying substantially more. This redistributive effect of sub-metering has caused significant discontent among the owners.

Figure 3: Density Distribution of Average Monthly Unit Electricity Costs: First Post-sub-metering Year Compared to 2005-March 2008



Source: unit costs post-sub-metering, building electricity costs 2005-08, allocation formula.

7. Cost-Benefit Analysis

We approach the cost-benefit analysis of sub-metering for this building in three different ways. First, we estimate the private costs and benefits for the condominium owners as a group, comparing what they paid post-sub-metering with an estimate of what they would have paid if sub-metering had not occurred. Second, we can calculate social costs and benefits using the regulated electricity price to represent the value of the electricity saved. Third, we can look for other measures of the value of the saved electricity.

Evaluating the private net benefits of sub-metering for the condo owners requires an estimate of the value of the electricity conserved less the costs associated with that conservation. On the benefit side, we value the electricity saved at the consumer price. This implies that benefits **B** equal the product of saved electricity **ΔQ** and the consumer price per unit **P**, which is the sum of the commodity price and the variable delivery charge. On the cost side there are increased fixed delivery charges **ΔF,** that we assume represent a real resource cost of sub-metering, and any lost consumer surplus (ΔCS). If demand is linear the standard calculation of lost consumer surplus is $\Delta CS = \frac{1}{2} P\Delta Q$. Thus net benefits are:

(3) $$NB = P\Delta Q - \Delta F - \Delta CS.$$

We use our regression results from equation 1 and Table 2 to forecast the monthly savings in building consumption which we multiply by the monthly commodity price. The delivery costs are more elusive because if bulk-metering had continued they would pay delivery charges based on the building peak consumption for any hour during the billing month. We don't know the building monthly peak post-sub-metering. Instead, we estimated the relationship between monthly kWh consumption and the delivery charges, both before and after sub-metering. The results are presented in Table 4. The variable total delivery charges for the building per kWh consumed are similar before and after sub-metering: 2.867 cents/kWh and 2.950 cents/kWh. We use 2.9 cents to represent the delivery charge saving attributed to the reduction in consumption in each month. The intercept in the regression represents fixed monthly delivery costs which have increased from $345 (statistically insignificant) to $1,206 per month. Over a year this represents an increase in of $10,332, about 7% of annual electricity costs. Net first-year private cash savings are $7,957 or 5.6%, a substantial reward for the 20% reduction in consumption. See Table 5.

The lost consumer surplus calculation requires further thought. The standard calculation for moving up a straight-line demand curve from zero price is $\Delta CS = \frac{1}{2} P\Delta Q$**.** Assuming that the price that residents respond to is the sum of marginal charges for kWh and distribution, then lost

Table 4: Delivery Cost Relationship to Monthly Building Consumption

	Marginal Cost $/kWh	**Fixed cost** $/month
Pre-sub-metering year	$0.02867*** [0.0059]	$345 [942]
Post-sub-metering year	$0.02950*** [0.0016]	$1,206*** [185]

*** statistically significant at the 1% confidence level; ** = 5%. Standard errors in brackets.

consumer surplus is $9,145. However the quick response and the concentration of conservation outside of winter suggests that conservation was achieved primarily by less intensive use of appliances and lights, perhaps turning them off when not in use. The disutility is probably less, perhaps much less, than the standard calculation. Perhaps the owners were indifferent to electricity waste before sub-metering and the conservation effort reduced pure waste with no loss of consumer surplus. We come down the middle and assume that lost consumer surplus is half the standard calculation or $4,572 ($\Delta CS = \frac{1}{4} P \Delta Q$) which yields a net benefit (NB = ¾*P*ΔQ-ΔF) of $3,385. See Table 5. Remarkably, despite the 20% reduction in electricity consumption in this building the owners have only modestly improved their welfare in aggregate because the electricity savings are largely offset by increased delivery costs and by the disutility arising from their conservation efforts.

Social cost-benefit analysis requires consideration of three further issues: whether part of the delivery charges represents economic rents rather than resource costs; whether the regulated price represents marginal generation costs; and what adjustment must be made for the environmental costs of generation.

Should we interpret the delivery charges in this case as resource costs or do they include some economic rents? We have no cost study for this supplier so we must examine the competitive conditions for sub-metering in Toronto. Metering of individual suites can occur in either of two ways. The regulated electricity distributor may install a meter for each suite and for the common areas, called 'suite metering.' These rates are regulated. (OEB 2009, p. 2.) Alternatively a sub-metering company may install meters for each suite and for the common areas leaving the bulk meter for the building in place, pay the regulated electricity distributor the

Table 5: Private Cost-Benefit Summary

Basis for savings	**Amount**
Commodity savings at RPP price	$12,415
Savings in variable delivery charges	$5,874
Increased fixed delivery charge	-$10,322
Net cash flow	**$7,957**
Lost consumer surplus (1/2 of standard calculation)	-$4,572
Net private benefits	$3,385

usual charges based on the bulk meter and charge the condo and the unit owners for their own electricity, called 'suite sub-metering.' This is what happened in our building. These rates are not regulated. The Ontario Energy Board has determined that these two methods of provision compete in the same market. (OEB, 2009, p. 5.)

Any electricity distributor may offer suite metering within its territory and Toronto Hydro offers this service, charging the same rates that it charges to residential customers. In addition, nineteen firms are licensed to offer sub-metering services in Ontario (OEB 2010a) of which websites suggest that eight are actively engaged in this service. Seven of these active firms are members of a Smart Sub-Metering Working Group that represents their interests at regulatory hearings. (OEB 2010b, p. 25.) This is a reasonably competitive structure and the excess of licences over active providers suggests that entry could occur easily. The OEB has found that the market is in fact competitive. (OEB 2010b, p. 25.) The pricing for these services, however, is not always transparent. Some sub-metering firms charge a fixed monthly cost per customer plus a variable fee based on peak demand. Rates are not published but must be negotiated by the customer and building boards will not be able to estimate the monthly cost of the fees without expert advice. A building board might secure two or three competing bids but unless they have the same price structure it will be difficult for the board to compare price levels. Moreover contract periods may extend to 25 years with the metering company having the right to change their rates subject to approval by the OEB. The complexity of pricing means that we cannot assume that customers are well informed and this gives the firms some degree of market power. On the other hand, the Smart Sub-Metering Working Group has accused the distribution firms of cross-subsidizing their suite metering rates (OEB, 2010b, pp. 25-30) which would limit the amount that the sub-metering firms could charge. The OEB has ordered a cost allocation study to determine whether Toronto Hydro is cross-subsidizing its suite metering rates and this study should help establish the real costs of suite and sub-metering. In the meantime, we assume that the market is sufficiently competitive that the distribution charges represent real resource costs.

Social cost-benefit analysis must also recognize that the regulated tiered electricity price may not represent time-varying short run marginal costs. We provide three alternative estimates to reflect: marginal costs of generation; environmental externalities; and displacing wind power paid for by Ontario's Feed-In Tariff. We use a more general equation for net benefits:

(4) $$NB = V\Delta Q - \Delta F - \frac{1}{4}P\Delta Q.$$

where V represents the per unit social value of the conserved electricity. Note that lost consumer surplus depends on the price paid, not the social value, and reflects our conservative estimate.

The marginal cost of electricity generation varies depending on the supply and demand for electricity, rising and falling by season, day and hour. Ontario's wholesale electricity market generates hourly prices that approximate the marginal cost of generation. If we ignore air pollution arising from electricity generation, we could use the average monthly wholesale price to approximate the social value of the conservation savings. These short-run prices are significantly lower than the regulated consumer prices post-sub-metering during our study period in part because sub-metering coincided with the recession that started in 2008 and reduced electricity demand, reducing marginal generation costs and wholesale electricity prices. We re-calculate monthly electricity savings using the monthly average wholesale electricity price in the 12 months since April, 2008 rather than the regulated price. The result, net of distribution cost changes is an insignificant gain of $368, less than 1% of the pre-sub-metering electricity cost. See Table 6. Sub-metering barely meets the social cost-benefit test if we value the electricity saved at actual marginal costs of generation during this particular year.

When the economy recovers the marginal cost should rise to the regulated price or more, causing social savings to reach or exceed private savings. Clearly any analysis of the social benefits of sub-metering needs to consider the time variation in local electricity marginal generation costs and the time pattern of conservation. We have not seen this analysis in any other paper. Because the low MC during our study period is transitory we calculate both the benefits based both on short-term MC and on the regulated price which is closer to (but probably below) MC over a range of economic conditions.

Another alternative valuation of electricity conservation recognizes that the price of electricity fails to include costs such as air pollution damage from fossil-fuelled plants and greenhouse gas emissions from those plants. These externalities could represent from one cent to ten cents/kWh depending on the type of fossil generation and the assumed value of CO_2. See Appendix B. In Ontario where demand reduction may reduce either coal-fired or gas-fired generation, we assume a low value of 2 cents/kWh and a high value of 8 cents/kWh. These values would increase the net benefits of conservation by approximately $4,000 and $16,000 per

Table 6: First-year Net Benefits from Sub-metering

Basis for calculating commodity savings	Commodity Savings[1]	Net Benefits[2]	Net Benefits as Fraction of Spending[3]
Retail Price Plan	$7,957	$3,385	2.38%
Marginal generation cost (HOEP)	$4,940	$368	0.26%
RPP w/ low pollution externalities	$12,008	$7,436	5.22%
RPP w/ high pollution externalities	$24,161	$19,589	13.75%
Displacing wind power at 13.5 cents/kWh	$22,886	$18,314	12.86%

1. Savings from of direct electricity charges and changes in delivery charges.
2. Commodity savings less lost consumer surplus of $4,573.
3. Pre-Sub-Metering average annual spending was $142,443.

year, respectively. (See Appendix B for explanation and calculation.) Including environmental considerations substantially increases the economic desirability of electricity conservation yielding positive net benefits for our building of 5% and 14% of baseline electricity costs and indeed it is environmental considerations that motivate many electricity conservation programs including sub-metering. Table 6 summarizes these results.

Another way to view the environmental consequences of this conservation is to assume that the government is choosing between contracting for more costly green power under the *Green Energy Act* versus sub-metering in buildings like this one. The Feed-In-Tariff offers 13.5 cents for land-based wind farms. If we value the saved electricity at 13.5 cents/kWh rather than the regulated price, the net social benefits from sub-metering are over $18,000 or nearly 13% of annual spending. Sub-metering is very attractive if we assume a high value for the environmental benefits of the resulting electricity conservation.

What can we infer from these results about the social net benefits of sub-metering for other buildings? For a simple analysis, we assume that sub-metering yields a 20% reduction in electricity consumption, as in our building, and that the prices of electricity and distribution are the same as in our building. The fixed costs of sub-metering mean that as consumption drops net benefits will diminish. We can calculate the baseline electricity consumption that would be needed to yield a social break-even by setting equation 4 equal to zero and solving for ΔQ. Table 7 shows the baseline consumption in kWh/year that yield zero net benefits for each of our valuation scenarios. Serious consideration of the environmental externalities can lead to break-even for a building with half our consumption.

Table 7: Break-Even Conservation Thresholds

Basis for calculating commodity savings	Break-even kWh[1]	Break-even/ baseline (%)[2]
Retail Price Plan	134,400	85.2%
Marginal generation cost (HOEP)	158,487	100.5%
RPP w/ low pollution externalities	106,653	67.6%
RPP w/ high pollution externalities	65,861	41.8%
Displacing wind power at 13.5 cents/kWh	68,708	43.6%

1. Calculations based on roots of equation (4)
2. Expressed as fraction of pre-sub-metering average annual usage of 1,577,000 kWh.

8. Conclusions and Implications

This study confirms that installing meters so that residents pay for their own electricity can achieve large reductions in electricity use in an all-electric building where the utilities for each unit can be privately metered. Annual electricity consumption was reduced by 20%. The reduction was greater in the summer than in the winter. The reduction was immediate, beginning with the first month of metering, suggesting that it was achieved mostly with behavioural changes. Both the magnitude of the conservation and its immediacy are consistent with industry statements about past experience. This, however, is the end of the good news. The electricity savings were substantially offset by increased delivery charges for each unit in the building to cover metering and billing costs. Assessing sub-metering requires careful analysis of these charges. The 20% reduction yielded net financial savings in our building of only 5.5%. Moreover if the conservation involves lost utility, deducting half of a standard calculation of lost consumer surplus leaves only modest increases in welfare for our owners.

Our findings parallel other studies in showing considerable variations in financial consequences among owners in the building. Owners whose consumption is more than their proportion of floor space in the building may pay more after metering than before even if they engage in some conservation. We find that basic unit characteristics allow us to predict relative consumption in a unit with reasonable accuracy. However a few units consume 50% less than our model predicts and a few consume 50% more, suggesting that individual lifestyles and/or some unobserved characteristics substantially affect consumption.

The timing of this metering project coincided with an economic slowdown that reduced marginal generation costs but not the regulated electricity price. If we value savings according to marginal costs, revealed by the wholesale electricity price, the social savings in generation costs were much less than 20% and net benefits were insignificant. On the other hand, the sub-metering project could have occurred when demand was high relative to supply in which case social savings would exceed those calculated at the regulated price. When analyzing a specific project, one should use marginal generation cost, if it is available.

Social benefit-cost analysis should also consider the reduction in air pollution and greenhouse gas damage arising from the electricity savings. These externalities can add substantially to the benefits of sub-metering, giving rise to net social benefits for this building ranging from 5% to almost 14% of pre-sub-metering costs. Substituting for expensive green power also yields large net social benefits.

This building configuration is ideal for sub-metering because it is all-electric and it has relatively large units and relatively high income occupants. A similar but smaller building might still yield positive net social benefits, if we consider environmental externalities in a jurisdiction with coal on the margin, even if baseline consumption is below 100,000 kWh/yr. We expect energy conservation to be smaller in buildings with central heating or central air conditioning or central hot water supply. Lower income buildings would yield less conservation and thus smaller benefits. Rental apartment buildings would present different problems in the longer run because sub-metering would attenuate the landlord's interest in installing energy-efficient appliances, windows and other energy-saving features. Further analysis would be needed to determine whether the social costs of sub-metering exceed the benefits in those buildings.

Overall, this study suggests that sub-metering will pass a social cost-benefit test for only a fraction of multiple-unit residential buildings, particularly all-electric higher-income condominium buildings, in a jurisdiction where a high value is assigned to greenhouse gas reductions and where coal-fired electricity is likely to be reduced by energy conservation. Because savings are greater in the summer, a warmer climate should yield better cost-benefit results. In many cases, the private financial impact on the residents may be negative until such time as pollution taxes or cap-and-trade pollution and greenhouse gas control regimes raise the price of electricity to fully reflect the externalities caused by generation.

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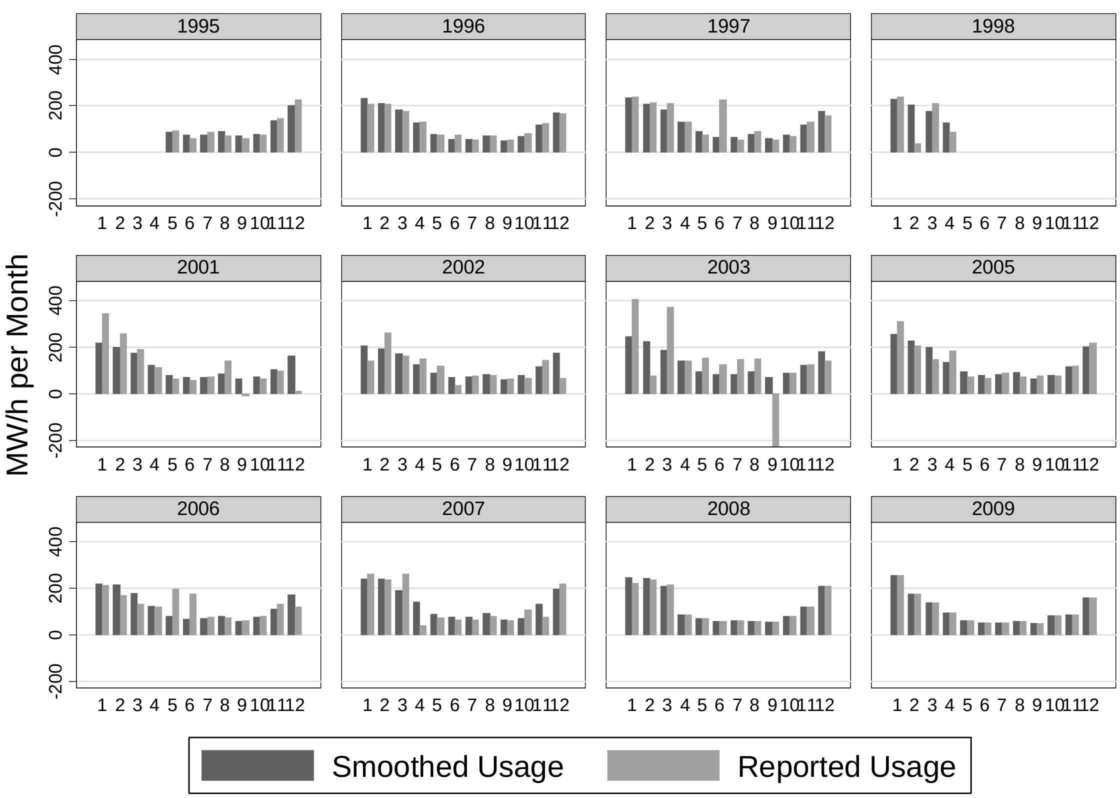
Appendix A: Smoothing of erroneous consumption data

The reported aggregate monthly consumption data for 1995-1998, 2001-2003 and 2005-March 2008, display clear signs of measurement error. There are numerous months with implausible levels of electricity usage (negative or close to zero in winter months, for instance). This is due to the estimation procedure used by the electrical provider in a month when the meter is not read. When the meter is read subsequently that later month is assigned an amount that leads to the correct total for the estimated moths, but if the first month was too high the next month will be too low or vice versa. To generate a series that better reflects the actual consumption for each month we use a statistical smoothing technique.

Outlier months are identified and their consumption is partially deleted from the data. Reported consumption that is very big, very small, or very different from the average for that month of the year is not used to estimate the first-round smoothed values. The definition for big/small/different is as follows: (1) the top and bottom 5% of reported monthly usages and (2)

Figure A1: Aggregate Monthly Consumption: Reported and Smoothed



the top and bottom 5% of usage for months that deviate from the unconditional average usage for that given month over the years for which we have data. The questionable data flagged under first criterion are a subset of those flagged by the second, with the addition of January 2005 and June 2002. We then replace the deleted values with the average for that month in all other years. However we do not ignore the questionable values. We save them and add back in the difference between the questionable value and the replacement value, spread over all months in a data series (e.g. 1995-98) in proportion to the first round smoothed values. In this way, the total electricity consumption for each data series is the same for the original data and the smoothed data. Visual inspection suggests that the smoothed data are a reasonable representation of the raw data. See Figure A1. We tested to see whether the results are affected by the application of the first criterion and found that the estimated effect of sub-metering is about 20% lower without applying the first criterion in the smoothing process.

Appendix B: Environmental Costs of Generation

The environmental benefit from electricity generation depends on which types of generation unit reduce their output. In Ontario the nuclear units and hydroelectric units have high capital costs and low operating costs so their output is not reduced as demand falls. Wind generation is accepted on the grid as it is available. Reduced demand thus may reduce coal or gas-fired generation. Since Ontario has committed to eliminating coal generation as soon as possible and no later than 2014, it is likely that general electricity conservation reduces coal generation. This is consistent with the large reduction in coal generation during the current economic slowdown.

Dewees (2008, Table 3) concludes that the social cost of air pollution from coal-fired plants in 5 ECAR states close to the great lakes is $32.81/MWh considering harm occurring in the airshed of those states and Ontario. A recent study for the US National Academy of Sciences concluded that the average externality from the emission of criteria pollutants from coal-fired power plants in the US was 3.2 cents/kWh, equal to $32/mWh. (US National Research Council, 2009, p. 6.) The population density of southern Ontario is sufficiently similar to that of much of the US to offer some confirmation of our estimate for the cost of traditional air pollution. To this we must add the social cost of greenhouse gas emissions. Many analysts believe that significant reductions in GHG emissions will require a price on CO2 of $25 or $50/tonne or more, which would give rise to total environmental costs in the range of $60-85/MWh or more.

If Ontario does close its last coal plant in 2014 the marginal generation will be natural gas. Because natural gas generation releases much less pollution than coal, the social cost of the non-GHG emissions is estimated at $0.52/MWh in 2004 $US. (Dewees, 2008, Table 3.) Natural gas generation emits CO2 at the rate of about ½ tonne/MWh which would add $12.50 or $25/MWh at CO2 prices of $25 and $50 respectively. Displacing gas generation could therefore be valued at $13 to $25.50/MWh displaced, dependent almost entirely on the greenhouse gas emissions.

We will use a low value of $20/MWh to represent displacement of natural gas generation and a high value of $80/MWh to represent displacement of coal generation. Each $10/MWh equals one cent/kWh, so these represent 2 cents and 8 cents/kWh respectively. In our building, savings of 202,549 kWh per year would give rise to environmental benefits valued at $4,050 or $16,200 respectively.