The Economics of Residential Water Heating:Fuel Choice, Economic Efficiency and Environmental Sustainability.

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1. SYNOPSIS

This paper discusses the impact of a utility fuel switching program on residential water heater fuel choice, economic efficiency and the environment.

2. ABSTRACT

Water heating accounts for about one-third of residential energy consumption in British Columbia.In British Columbia, natural gas is the dominant water heater fuel in single family dwellings, largely because it has advantages in terms of operating costs and recovery time. However, electricity is still a significant water heating fuel in multifamily apartment housing despite its higher operating costs.This is due to market barriers, that is the inability of developers to recover higher incremental capital costs for natural gas water heaters.To overcome this barrier, B.C.Hydro and the gas utilities have provided incentives for the installation of natural gas water heaters through the Residential Natural Choice pilot.

This paper reports on the evaluation of the Residential Natural Choice pilot. It focusses on three key issues: the determinants of water heater fuel choice; the costs and benefits of the pilot in terms of economic efficiency; and the impact of the pilot on environmental sustainability. Three main methodologies are used: discrete choice modelling; cost benefit analysis; and engineering algorithms.

Key findings include the following.First, relative capital costs of the water heaters, relative fuel prices and dwelling characteristics are the main determinants of water heater fuel choice.Second, the pilot was cost effective from the perspective of the Participant Test, the Utility Test and the Total Resource Cost Test.Third, the pilot was not cost effective, given B.C.Hydro's fuel mix, from the perspective of the Societal Test which includes the effects of greenhouse gases and local emissions.These findings have significant implications for future fuel switching programs.

3. INTRODUCTION

Natural gas has made considerable inroads in British Columbia for space and water heating in single family dwellings due to cost and efficiency advantages.Natural gas has achieved only limited penetration in apartments because of market barriers.The most important market barrier is the problem developers have in recouping higher capital costs for natural gas space and water heating through higher selling prices or higher monthly rents.

B.C.Hydro, and the gas utilities in British Columbia have addressed the factors constraining increased use of natural gas in multifamily residential construction through a pilot fuel switching incentive program.This pilot subsidized installation of natural gas space heating and water heating in new multifamily residential construction.

This paper reports key results of the evaluation of the pilot. The outline of the paper is as follows.The next section provides a brief overview and description of the pilot program.The following four sections deal with the study approach, water heater fuel choice, costs and benefits, and environmental impact.The final section discusses conclusions and implications.

4. BACKGROUND AND PILOT DESCRIPTION

4.1 BACKGROUND AND RATIONALE FOR THE PILOT

Natural gas has several advantages over electricity as a heating fuel in British Columbia.First, even allowing for its higher initial or capital costs, natural gas has lower life cycle costs than electricity over the lifetime of the equipment.Second, if the incremental source of electricity is thermal generation, it is generally more efficient to burn fuel directly for heating rather than indirectly by first producing electricity.Third, burning natural gas directly for heating purposes may result in a lower volume of harmful emissions.

Despite these advantages, natural gas has achieved only limited penetration in multi-family apartment dwellings.The main reason for this was the substantially higher capital cost of installing natural gas rather than electric water heating equipment.It is apparently difficult for developers to recoup the higher capital costs through either a higher selling price (for condominiums) or higher monthly rents (for rental apartments).(Canadian Resourcecon 1991).

4.2 PILOT DESCRIPTION

The Residential Natural Choice pilot began in September 1991 and remained openfor subscription until March 1992.The goals of the pilot were to promote natural gas as a space and water heating fuel in new residential multifamily dwellings and to gain an understanding of the impact of alternative incentive levels on developer fuel choice.

The design of the pilot emphasized several key features.First, the cost of incentives were shared between B.C.Hydro and the three gas utilities, with B.C.Hydro contributing about two dollars for every dollar contributed by the gas utilities.Second, to get as wide a range of experience as possible, the pilot was not limited with respect to location, although marketing efforts were focussed on the Lower Mainland, i.e., Vancouver, its suburbs and the Lower Fraser Valley.Third, incentives offered per unit were deliberately varied for different developments in order to test market acceptance at various rebate levels.Fourth, the program was targeted at apartment developments, although one rowhouse development also participated.

Major developers were personally approached and given information on the nature and purpose of the pilot.Developers had to ensure that buildings participating in the pilot used natural gas for both water heating and space heating.If natural gas fireplaces were installed, they had to have an efficiency of at least 65 percent.Proposals from developers were carefully reviewed, particularly with a view towards an accurate understanding of the likely reduction in electricity consumption and the associated capital costs.A decision was then made on what incentive, if any, to offer a developer.Initial interest was expressed for about 30 developments with offers made for 21 of these and agreements concluded for 15 projects.Fourteen of these agreements were for apartment projects and one was for a rowhouse development.Before the rebate payment was made, an inspection was undertaken and suitable documentation completed.

5. EVALUATION ISSUES AND APPROACH

This study examines three main issues:

- determinants of water heating fuel choice;
- costs and benefits of the Residential Natural Choice pilot;
- environmental impacts of the pilot in terms of quantities and costs of greenhouse gases and local emissions.

In analyzing these issues, a multiple lines of evidence approach was used. A variety of data sources were used to compensate for the fact that no single source provides adequate information on all of the evaluation issues of interest.Three data analysis techniques were used, each technique being used to address one or more evaluation issues.Table 1 summarizes the evaluation issues, data sources and methodologies for this study.These are discussed in detail below.

Table 1. Evaluation Issues, Data Sources, Methodologies

Evaluation Issue	Data Sources	Methodologies
1. Determinants of water heating fuel choice	.Program records .Survey of program clients .Baseline surveys	.Probit model
2. Costs and benefits of the pilot	.Program records .Survey of developers .Site audits	.COMPASS model
3. Environmental impacts of the pilot	.Program records .Site audits	.Engineering algorithms

6. WATER HEATER FUEL CHOICE

6.1 MODEL AND DATA

A number of previous studies have examined fuel choice in residential households (Cambridge Systematics 1982 and 1984; Dubin and McFadden 1984; Gately 1980; Goett 1978; Hausman 1979; Tiedemann 1994).Typically these studies have estimated logit or multinominal logit models using national samples of household data on fuel prices, fuel use and appliance saturations.These studies have found that fuel prices and capital costs are major determinants of household fuel choice.

In modelling water heating fuel choice, a discrete choice model is needed since builders and developers have a finite number of alternatives from which to choose.Since fuel oil and propane are no longer significant alternatives in the Lower Mainland of British Columbia, developers and builders have natural gas or electricity as their water heating fuel choices.The dependent variable is thus binary; it takes the value "1" if natural gas is the water heating fuel and "0" if electricity is the water heating fuel.Review of the relevant literature cited above together with interviews with developers, builders and utility staff suggests that several factors are major determinants of water heating fuel choice.Variables included in the model and sample characteristics are given in Table 2.

Table 2. *Definition of Variables and Sample Characteristics (n=132 developments)*

Variable	Definition
Water heat	Natural gas water heating = 1, electric water heating = 0 (Mean = .727)
Incap	Incremental capital cost of using natural gas water heating in 1992 Canadian dollars (mean = $312)
Fuelsav	Incremental fuel saving of using natural gas water heating in 1992 Canadian dollars. (mean = $85)
Row	Rowhouse development = 1, apartment development = 0 (mean = .288)
Units	Number of housing units in the development (mean = 76.7)
Tenure	Owner occupied unit = 1, rental unit = 0 (mean= .667)

The first variable affecting water heating fuel choice is the incremental per unit capital cost of natural gas water heaters above that for electric water heaters, net of incentives received.This incremental cost has three main components:$50 additional cost for the water tank; $100 for additional installation costs; and costs of providing gas service of $250 for apartment units and $300 for rowhouse units.Discussions with developers indicated that decisions on space heating choice were typically made prior to those on water heater choice, so the additional gas service component was set at zero for developments with natural gas space heating.The expected sign of the coefficient on this incremental capital cost variable is negative.

The second variable is the incremental annual fuel saving of using natural gas instead of electricity.Previous research indicated that average annual fuel use for water heating is about 19.52 GJ or about 4658 kW.h.Savings were estimated as (4658* price of electricity) minus (19.52* price of natural gas).Given the typical 12 month lag from project design to completion, energy prices prevailing about 12 months before project completion were used.Expected sign of the coefficient on incremental annual fuel saving is positive.

The third variable is a dummy variable for a rowhouse development, i.e. not an apartment development.Rowhouses are more likely than apartments to be upscale, expensive units and thus more likely to have natural gas space heating which is viewed as an attractive feature.Expected sign of the coefficient on the rowhouse dummy variable is positive.

The fourth variable is the number of housing units in the development.In larger developments, the developer is able to spread the higher fixed costs of natural gas water heating over a larger number of units.Expected sign of the coefficient on this variable is positive.

The fifth variable is the type of tenure.In owner occupied developments, the owner is able to capture the benefit of lower energy costs and has an incentive to have natural gas water heating despite its higher capital costs.In renter occupied developments, where typically the renter is responsible for energy costs, the owner is not able to capture the benefit of these lower energy costs.This is sometimes referred to as split incentives.Expected sign of the dummy variable representing tenure is positive.

The sample used in this study includes 132 apartment or rowhouse developments for which appropriate data was available from studies conducted by B.C.Hydro (including the 21 developments for which an offer was made).These apartment and rowhouse developments were completed in the years 1990 through 1994.It was necessary to use data from several years because in any given year all developments faced the same energy rate schedules.It should be noted that the unit of analysis used here is the development, not the individual housing unit, since decisions on water heating fuel choice are made by the builder or developer for all of the units in a given development.

6.2 ESTIMATION METHOD AND RESULTS

Because the dependent variable (water heating fuel) is a binary variable, the model was estimated using probit regression.The probit model takes into account the discrete nature of the dependent variable and possesses better statistical properties than ordinary least squares in this context (Amemiya 1984, Johnston 1984).The model was estimated by maximum - likelihood using the Newton-Raphson method.The likelihood function converged in seven iterations.

Regression results are shown in Table 3.All of the coefficients have the expected signs, i.e. fuel savings, housing type, number of units and owner occupied all have a positive effect on selection ofnatural gas water heating while higher incremental capital costs for natural gas has a negative effect on selection of natural gas water heating.The asymptotic t-statistics are shown below the coefficients.All of the coefficients except housing type are significant at the ten percent level.

Table 3. *Water Heater Choice Model (probit estimates, dependent variable is natural gas water heating = 1, electric water heating = 0, n = 132 developments)*

Variable	Coefficient	Partial Effects
Incap	-.0131***	-.00221
	(-3.951)	
Fuelsav	.0433***	.00730
	(2.907)	
Row	.3660	.06164
	(.849)	
Units	.0144***	.00243
	(3.862)	
Tenure	.7243*	.12198
	(2.038)	
Log-likelihood	-43.73	

Asymptotic t statistics are in parentheses
**Significant at 10% level*
****Significant at 1% level*

Since there is no goodness of fit measure for the probit model, a "score" is calculated using the following rule:"predict y = 1 if the predicted probability for natural gas space heating is greater than .5, predict y = 0 otherwise."Using this rule 109 out of the 132 choices or about 83 percent are predicted correctly by the model.

The marginal or partial effect of the dependent variables in the probit model are also given in Table 3.Since the probit model is highly nonlinear, the partial effects are not the regression coefficients but instead the partial derivatives of the relevant expectation.These are evaluated at the sample mean in the usual way.Several points are worth noting here.First, a larger incentive reduces incremental capital costs of natural gas water heating.In other words, increasing the incentive paid by utilities significantly increases penetration of natural gas water heating for this sample.Second, the ratio of the coefficients Incap to Fuelsav can be interpreted as the average, implicit discount rate applied to this fuel choice decision (Cambridge Systematics 1984).This implicit discount rate is about 30 percent.Third, owner occupied units are more likely to use natural gas water heating.The positive and significant coefficient on the tenure variable is consistent with the split incentives hypotheses.

7. COSTS AND BENEFITS OF THE PILOT

7.1 COST TESTS AND DATA

This section considers the impact of the pilot in terms of economic efficiency.Following standard practice, a variety of cost-benefit measures are presented which consider the project from the perspective of various stakeholders.Five tests are considered:the utility test, the rate impact measurement test, the participant test, the total resource cost test and the societal test.The benefits and costs considered in each of the five tests are shown in Table 4.Tests can be reported either on a net present value basis (i.e. benefits minus costs) or a benefit/cost ratio basis (i.e. benefits divided by costs).The utility test compares avoided supply costs [i.e. (change in energy produced times marginal costs of energy) plus (change in capacity required times marginal value of peak savings)] to incentives paid out plus utility program costs.The rate impact measure test compares avoided supply costs to the sum of (net) revenue losses plus incentives paid out plus utility program costs.The participant test compares the sum of bill reductions, incentives received and tax credits (such as sales taxes on energy) with participant costs (i.e. technology acquisition costs).The total resource cost test compares the sum of avoided supply costs and tax credits to the sum of participant costs and utility costs.The societal test compares the sum of avoided supply costs and external costs to the sum of participated costs, utility costs and external benefits.

***Table 4.** Benefit Cost Tests*

Test	Benefits	Costs
Utility	.Avoided supply costs	.Incentives .Utility Costs
Rate Impact	.Avoided supply costs	.Revenue loss .Incentives .Utility costs
Participant	.Bill reductions .Incentives .Tax credits	.Participant costs
Total Resource Cost	.Avoided supply costs .Tax credits	.Participant costs .Utility costs
Societal	.Avoided supply costs .External benefits	.Participant costs .Utility Costs .External Costs

Estimates of increased natural gas consumption and reduced electricity consumption were based on a combination of engineering and site visit data.Before a participation agreement was signed, the developer had to provide heat loss estimates which were used to estimate energy consumption for space heating, domestic hot water and ventilation.These were used to estimate natural gas and electricity consumption (depending on whether the building used natural gas for these purposes or not).To improve these estimates, eight of the fifteen projects received a detailed site audit after completion.The site audits produced detailed estimates of increased natural gas consumption and reduced electricity consumption due to fuel switching.Standard ASHRAE methods were used to provide these estimates.Estimated impacts for the seven projects which were not site audited were produced by applying the average ratio of pre-audit to post-audit estimates to the pre-program estimates for projects not audited.Capacity savings were based on typical load shape data.

Marginal costs for electricity and natural gas used long-run marginal costs of new supply from B.C.Hydro and B.C.Gas.These figures include appropriate costs for production, transmission and distribution, including average system-wide losses in transmission.Incentives paid and utility program costs were based on program records.Revenue losses (for electricity) or gains (for natural gas) were based on projected rates from the utilities.Bill reductions or increases are just the negative of revenue losses and gain.Incremental capital costs for the fuel switching (i.e. participant costs) were discussed in the previous section.Tax credits were based on present sales tax schedules.There were no external benefits identified and external costs are discussed in the next section.

7.2 COST-BENEFIT RESULTS

The cost-benefit analysis was undertaken using COMPASS software.In addition to the data sources noted above the following assumptions were made:

- time-frame - a 30 year time horizon was employed for the analysis.It was assumed that water tanks would be replaced after ten years and major gas system servicing would be required at 20 years;
- free-riders - survey information collected during site visits suggested that three of the fifteen buildings would probably have had natural gas water heating in the absence of the program, so fuel savings, capacity savings and revenue losses (gains) were based on adoption rates net of free riders;
- discount rate - for the net present value calculations, a discount rate of eight percent was used (this is B.C.Hydro's long term marginal cost of capital).

The results of the COMPASS runs are shown in Table 5.The pilot has a benefit/cost ratio greater than one and a positive net present value in terms of the utility test (B/C=1.25, NPV=$301,400), participants test (B/C=1.10, NPV=$222,400) and the total resource cost test (B/C=1.06, NPV=$94,500).In other words, the pilot was cost effective from the perspective of the utilities involved, program participants and the economy as a whole, if externalities are not considered.However, the pilot has a benefit/cost ratio less than one and a negative net present value in terms of the rate impact measurement test (B/C=.96, NPV-$127,900), so that rate payers as a whole would see an increase in their energy rates.The societal test is discussed below.

Table 5. Benefit Cost Analysis

	Net Present Value ($000)	Benefit Cost Ratio
Utility Test	301.4	1.25
Rate Impact Test	-127. 9	0.96
Participants Test	222.4	1.10
Total Resource Cost Test	94.5	1.06
Societal Test	-283.6	0.82

8. ENVIRONMENTAL IMPACT

Production, transmission, distribution and utilization of different fuels leads to a variety ofenvironmental impacts and costs.For natural gas and electricity, the key impacts and costs are those resulting from resource losses due to dam construction and reservoir flooding and emissions from the production, processing and combustion of fossil fuels.

B.C.Hydro produces most of its electricity with hydro-electric generation, although this is supplemented by production of the Burrard thermal plant as well as a number of smaller facilities which are not part of the integrated power grid.B.C.Hydro's social costing framework includes externalities in the marginal cost of electricity supply used above.External costs of lost land are estimated by the market value of the lost land.The marginal cost of electricity also includes a cost component for natural gas burned at the thermal plant.The marginal costs for electricity used in the total resource cost test then is already inclusive of average system external costs for electricity.

The main concern here is thus the external costs arising from increased consumption of natural gas used for water heating.Environmental impacts or external costs are calculated using the following formula:external costs ($/GJ) = emission factor (kg/GJ) * unit emissions costs ($/kg).

The principal emissions associated with natural gas use are the following (Bridges 1991):

- carbon dioxide (C02) - carbon dioxide is the principal greenhouse gas, and a major source of increased concentrations of carbon dioxide in the atmosphere is consumption of fossil fuels;
- Sulphur dioxide (S02) - sulphur dioxide can cause respiratory problems, reduce visibility and damage plant life and surfaces of materials;
- nitrous oxides (N0X) - nitrous oxides are a significant greenhouse gas and contribute to acid rain formation;
- methane (CH4) - methane is the second most important greenhouse gas, after carbon dioxide;
- carbon monoxide (CO) - carbon monoxide is similar to carbon dioxide in its effects as a greenhouse gas;
- volatile organic compounds (VOC) - volatile organic compounds are ozone precursors and also lead to possible respiratory and other health effects;
- particulate matter (PM) - particulates are solid matter suspended in the atmosphere and have possible health effects.

Emission factors and emission costs for natural gas are shown for these seven classes of emissions in Table 6.The emission factors and emission costs are based on Bridges 1991, which used estimated costs of controlling the pollutent as a proxy for pollutant damage costs.External costs for each class of emission are given in the last column of this table.The estimated external cost for natural gas is about $1.27/GJ.The three main contributions are carbon dioxide ($.81/GJ), sulphur dioxide ($.32/GJ) and nitrous oxides ($.10/GJ).These three pollutants account for over 95 percent of the estimated external cost of natural gas.To keep this cost in perspective, it can be compared with residential natural gas costs of about $4.85 in 1992.

Table 6. *External Cost for Natural Gas*

Emission	Emission Factor (Kg/GJ)	Emission Cost ($/Kg)	External Cost ($/GJ)
C02	56	.0145	.812
S02	.066	4.894	.323
N0X	.086	1.201	.103
CH4	.057	.160	.009
CO	.0168	.0435	.001
Volatile Organics	.0084	2.20	.018
Particulates	.0003	2.092	.001
Total			1.267

Incorporation of these externality estimates substantially changes the cost benefit results.On a societal basis, i.e. adjusting total resource costs by the emissions externalities (and the relatively small change in taxes) leads to a net present value of
-$283,600.The benefit cost ratio for the societal test is only .82 compared to 1.06 for the total resource cost test.In other words, although the program appears to be cost effective on a total resource cost basis,it is not cost effective when environmental externalities are considered.

9. SUMMARY AND IMPLICATIONS

This paper illustrates how discrete choice modelling and cost benefit analysis can be used to analyze a fuel switching demand side management program.The study has three key findings.First, incremental capital costs net of incentives, expected fuel savings, size of the housing development and type of tenure are all significant determinants of water heater fuel choice.These results suggest that larger incentives encourage installation of natural gas water heaters and that there is evidence of a split incentives market barrier. Second, the project was cost effective from the perspective of the three most widely used cost tests:the utility test, the participant test and the total resource cost test.The benefit/cost ratio was greater than one for each of these three tests.Third, the project was not cost effective from the perspective of the societal test which incorporates externalities, given B.C.Hydro's fuel mix.This result is driven by the fact that B.C.Hydro produces most of its electricity from hydro-electric power.For coal fueled utilities, this type of fuel switching could well provide net environmental benefits rather than net environmental costs.

These findings have several implications for planning future fuel switching programs.First, it is important to carefully identify the target market.In the case of the Residential Natural Choice pilot, the program was most successful in encouraging natural gas water heating in larger developments.Second, it is important to analyze fuel switching programs from the perspectives of all stakeholders - utilities, program participants and general ratepayers.Fuel switching programs can have quite different equity implications for these various groups.Third, analysis of fuel switching programs needs to consider environmental factors.Consideration of emissions, in particular, are critical in evaluating fuel switching programs.

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