HOME ENERGY PREFERENCES & POLICY: APPLYING STATED CHOICE MODELING TO A HYBRID ENERGY ECONOMY MODEL

by

Margo Sadler
B. Business Administration, Simon Fraser University, 1998
C.A., Canadian Institute of Chartered Accountants, 1999

RESEARCH PROJECT
SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF RESOURCE MANAGEMENT

In the School of Resource and Environmental Management
Project number: 342

© Margo Sadler 2003
SIMON FRASER UNIVERSITY
September 2003

All rights reserved. This work may not be
reproduced in whole or in part, by photocopy
or other means, without permission of the author.

APPROVAL

Name:	**Margo Christine Sadler**
Degree:	Master of Resource Management
Title of Research Project:	Home Preferences & Policy: Applying Stated Choice Modelling to a Hybrid Energy Economy Model
Project number:	342
Chair:	**Maggie Tisdale**

Examining Committee:

Dr. Mark Jaccard
Professor,
School of Resource and Environmental Management, SFU

Ken Tiedemann
President,
Applied Economics Consulting

Bryn Sadownik
Research Associate,
Energy and Materials Research Group, SFU

Date Approved: September 24, 2003

PARTIAL COPYRIGHT LICENSE

I hereby grant to Simon Fraser University the right to lend my thesis, project or extended essay (the title of which is shown below) to users of the Simon Fraser University Library, and to make partial or single copies only for such users or in response to a request from the library of any other university, or other educational institution, on its own behalf or for one of its users. I further agree that permission for multiple copying of this work for scholarly purposes may be granted by me or the Dean of Graduate Studies. It is understood that copying or publication of this work for financial gain shall not be allowed without my written permission.

Title of Project

Home Energy Preferences & Policy: Applying Stated Choice Modelling to a Hybrid Energy Economy Model

Author:

(signature)

Margo Sadler

September 24, 2003

(date)

ABSTRACT

In this study I design and administer two discrete choice experiments to 950 homeowners across Canada to better understand consumer preferences for home renovations and heating systems. Using stated preference data from over 600 completed surveys, I estimate discrete choice models that provide market shares, time preferences and intangible costs or benefits for heating system and renovation choices in the residential sector.

Overall, respondents prefer energy efficient renovations to renovations without energy retrofits, indicated by a market penetration rate of 59% for the energy efficient renovation. Respondents use an average discount rate of 20.79% when trading off the capital cost of renovations with annual heating cost savings. Assuming consumers perceive the energy efficient renovation to have higher air quality than renovations without energy retrofits, energy efficient renovations have an annual intangible benefit of $1278.

Market shares by heating system technology are as follows: 17% for standard efficiency gas furnaces, 42% for high efficiency gas furnaces, 6% for electric baseboards, 28% for heat pumps and 10% for mid efficiency oil furnaces. For heating system choices, respondents use a discount rate of 9%. I assume that lower efficiency heating systems are less responsive compared to high efficiency heating systems, thus standard efficiency gas and oil furnaces have a $46 annual intangible cost.

These outcomes are the empirical basis for the values of key parameters in the CIMS energy economy model for simulating GHG reduction policies in a behaviourally realistic context. The first policy simulation, a $1000 subsidy for home energy retrofits, is effective at reducing GHG emissions in the residential sector by 10 to 16 per cent, however, the cost of such a program is prohibitively high. High efficiency heating system subsidies only produce a minor reduction in emissions. Regulations eliminating mid efficiency natural gas heating systems cause a small reduction in CO2 emissions but result in an increase in other GHG emissions (e.g. CH4 and N2O) as consumers switch to heating sources (e.g. oil and wood) with higher concentrations of these GHGs. My simulation of renewable portfolio standards showed little effect on the electricity prices in the residential sector.

DEDICATION

To my father, whose strength in the face of challenge and adversity constantly inspires me to bring those things initially out of reach, well within my grasp.

ACKNOWLEDGEMENTS

Thank you to my husband, Karl, my parents, Sandra & Al and my sister, Shannon for endless support and encouragement. Thank you to Mark Jaccard for his insight to see the potential in this project as well as in me! Thank you to all my friends and colleagues at REM and EMRG for smoothing over the rough spots! And special thanks to Matt Horne, Nic Rivers, Bryn Sadownik and Ken Tiedemann for their untiring patience and persistence in seeing me through to the end!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

AEEI	Autonomous Energy Efficiency Index
AFUE	Annualized Fuel Utilization Efficiency
ASC	alternative specific constant
CEOU	Canada's Emissions Outlook Update
CIMS	Canadian Integrated Modeling System
CO2	carbon dioxide
ESUB	Elasticity of Substitution
GHG	greenhouse gas
LCC	life cycle cost
MNECH	Model National Energy Code for Houses
R2000	National home standard for energy efficiency and healthy design
RP	revealed preferences
RPS	renewable portfolio standard
RUT	Random Utility Theory
SP	stated preferences
VOC	volatile organic compounds

CHAPTER ONE
INTRODUCTION

1.1 Background to this research project

With the ratification of the Kyoto Protocol, Canada has committed to mitigate the effects of climate change through the implementation of domestic policies aimed at reducing GHG (GHG) emissions. Considerable effort has been put into formulating action plans and a national climate change strategy that encompasses all economic sectors; however, this planning effort has met resistance from various interest groups, provincial governments and industries. Underlying the debate between pro and anti-mitigation groups is the cost to society to implement such policies. Thus policy makers need to evaluate GHG reduction policies based on the true costs and choose within some acceptable range of uncertainty the policy package that minimizes the costs borne by society while still achieving the objective reductions.

Certain policies are more favorable to policymakers than others. For example, voluntary and informational programs that attempt to influence the behaviour of consumers or organizations are often given first consideration because they are non-obtrusive and relatively inexpensive. However, the success of these types of programs at achieving significant behavioural transformations is questionable (Jaccard & Bataille, 2003). To achieve the reductions required by Kyoto, not to mention future reductions, such passive policies barely scratch the surface. Given the magnitude of reductions required and the policy-makers' desire to implement palatable policy, attention turns to such policies as regulations and subsidies to improve the efficiency of the energy system and to encourage the transition to alternative sources of energy.

Because energy efficiency provides the advantages of cost optimization and does not require any level of curtailment of energy service, energy efficiency advocates and governments are convinced that increases in energy efficiency must be a key component of GHG reduction policy. Policy aimed at reducing emissions from fuel sources by transitioning to lower emission fuels or sequestering high emission fuels is another alternative that does not affect the level of energy services currently provided. The most effective mix of policies, whether they target energy efficiency, fuel emissions or both, cannot be determined without knowing the true (i.e. behavioral) costs that underlie such actions. The goal of this research is to assess how the integration of the behavioral and technical aspects of costs may influence the choice of energy policy. In this way I harness the advantages of both top-down and bottom-up modeling methodologies by using a hybrid model that explicitly accounts for both types of costs in the resulting actions. This research project provides an empirical basis for the estimation of behavioral costs of energy efficiency investment and fuel switching in the residential sector.

1.2 Organization of the paper

In the remainder of this chapter, I explain the focus of the research project, explore why behavioral costs are so important to policy analysis, particularly in the context of GHG reduction programs in the residential sector, and review current modeling methods and research on residential energy behavior. I conclude Chapter 1 by formally stating the research objectives of this project.

In Chapter 2, I describe the selection of the discrete choice experiment as the basis for empirical analysis of consumer preferences. I discuss how the results from the experiment form the basis of a discrete choice model. I then specify the type of discrete choice model used in my analysis. I conclude this chapter by describing in detail the discrete choice experiment and survey design, sampling criteria, survey fielding process and experimental design.

In Chapter 3, I present all results from the survey, estimate discrete choice models using data from the choice experiments and discuss the implications of the results for home energy policy.

In Chapter 4, I combine the results from the estimated discrete choice model with a hybrid energy economy model (CIMS) to simulate a variety of home energy policies. The chapter commences with a discussion of methodology to establish a link between the two models, followed by the establishment of a baseline scenario in the simulation model using the empirically estimated parameters. The new baseline is compared to various policy scenarios: subsidies, regulation, and increased energy prices via a renewable portfolio standard, to determine the impact on costs of climate change mitigation programs.

In Chapter 5, I discuss the limitations of the current research project, directions for future research and key conclusions.

1.3 Rationale for the focus of this research project

From the Kaya Identity decomposition equation, four factors contribute to the level of GHG emissions: the source of energy or percentage of fossil fuels in the energy mix, the energy intensity of economic output (including but not limited to energy efficiency and certain lifestyle changes), the standard of living (measured in terms of monetary economic output) and human population (cited in Jaccard, et al, 2002). GHG emission reductions can be achieved through modification of any of these factors, but not without the support of the general public. Therefore assuming that any modification to the standard of living or population would not gain widespread approval, and for the purposes of this research, GHG emissions are related to the overall consumption of energy, as determined by the energy efficiency of equipment and durables such as home construction, and the preferred fuel source.

The role of energy efficiency and fuel preference in GHG reduction

Among the various actions available to reduce GHG emissions, energy efficiency improvements to home heating services are particularly desirable because they are generally thought to be more acceptable to the public than other personal actions such as mode switching in transportation (Poortinga, et al, 2003). By increasing the energy efficiency of consumers' choice of heating equipment, home insulation levels and other structural characteristics contributing to energy consumption in the home, GHG emissions can be reduced while maintaining the same level of service to the consumer. Such a "win-win" scenario is highly desirable to policy makers. The potential energy savings related to improving the efficiency of existing housing stock and heating equipment adds to the desirability of such an action. For example, the existing stock of houses built before 1980, when many of the home energy conservation programs commenced, represents over 70% of the total housing stock, much of which has probably never been upgraded to current energy efficiency standards (NCCP, 1999a). The Office of Energy Efficiency estimates that older homes lose

25% to 40% of heat through air leakages from the shell of the home (for example, inadequate insulation, single-paned windows, inadequate weather-stripping). Older homes use greater than 30% more energy than homes built to the R2000 standard (OEE, 2003). The same potential energy savings for energy efficiency retrofits in the home exist for heating equipment. Although the adoption of more efficient heating equipment has been a growing trend since the implementation of standard efficiency regulations in the mid to late 1990s, only 36% of heating equipment in homes in 2000 was high efficiency (e.g. greater than 90% efficient) (NEUD, 2002).

The efficiency of the home shell and heating equipment contributes to the costs of space heating, which combined with water heating, accounts for more than 80% of home energy use (NRCan, 1999). Overall, the efficiency gains that could be made from shell and furnace improvements are significant enough to achieve 46% of the emission reductions required for the residential sector under Kyoto (Jaccard et al, 2002).

The other significant source of GHG emission reductions in the residential sector comes from fuel switching. Jaccard et al (2002) estimate that fuel switching accounts for up to 43% of the emission reductions required under the Kyoto Protocol in the residential sector. As the fuel source and the efficiency of equipment are key aspects of reducing emissions related to space heating in the residential sector, I have chosen to focus my research on these issues to better understand the behavioral factors that drive the decisions that consumers make and how these factors might be incorporated into policy analysis of GHG reduction programs.

Uncertainty of costs of implementation

Considerable argument and uncertainty regarding the costs of implementing GHG reduction actions intensified during the debate of ratification of Kyoto. Policymakers may understand that the true costs to reducing GHGs include both a financial cost and a welfare cost; however, quantifying the welfare costs has proved difficult as welfare cost includes all of the loss in consumer value individuals experience when forced or encouraged to make a behavioural change. Of the different cost components, the intangible cost or behavioural component is the least supported by empirical research. Therefore significant efforts in research have developed to address this issue, but first it is necessary to understand why behavioral costs are important to policy analysis.

1.4 Why are behavioural costs important to policy analysis?

We have the technology available for more efficient energy use and cleaner energy use. Some would even argue that financially it makes sense to switch to these cleaner, more efficient technologies. So why haven't we been able to bridge the gap?

This energy efficiency gap has been attributed to certain market failures, which require government intervention and non-market failures, which do not (Jaffe & Stavins, 1994). Sources of market failures that pertain to energy efficiency investment include under-provision of information by the market, principal-agent problems where the energy efficiency decision is made by a person other than the individual who pays the energy bills, distortions in energy prices due to selling at average cost rather than marginal cost, and continuing subsidization of well established inefficient technologies. Non-market failures contributing to consumer resistance to investing in energy efficiency include high information search costs, irreversible investment risk, payback uncertainty, future energy price uncertainty, uncertainty in estimated life-cycle savings, general inertia on the part of the consumer and heterogeneity among potential adopters. Thus the behaviour and perceptions of the consumer contribute significantly to the cost of adoption beyond what strict financial analysis estimates the costs to be.

Governments, utilities and researchers have attempted to bridge the energy efficiency gap for over 30 years. In the residential sector, various demand side management programs have been implemented to provide information and tangible incentives to consumers to invest in energy efficient technology. The federal government's EnerGuide program was introduced in 1978 to provide information to encourage the adoption of more energy efficient appliances to reduce energy demand (NRCan, 1994). Recently, Nanduri et al. (2002) undertook a stated preference discrete choice survey to evaluate the effectiveness of the EnerGuide labelling program in influencing consumer choices. While the results of the study did show a positive effect for labeling programs on consumer utility, the effect was small. This suggests that the market failure of underprovision of information is only a small component of a complex relationship between the consumer and the market.

Thus it is critical that successful policy analysis includes the estimation of intangible costs. The selection of the method to quantify these intangible costs is a debated topic among economists and behavioural researchers. The researcher can examine actual market data and draw inferences about consumer behaviour from "revealed preferences" or the researcher can ask the consumer to choose among a set of alternatives and draw inferences about consumer behaviour from "stated preferences". The advantages and limitations of each method are examined in the next section to develop a case for using a stated preference approach to further home energy research.

1.5 Current methods & research on residential energy behaviour

Revealed preferences versus stated preferences

Traditionally viewed by some observers as a methodology of questionable validity and reliability, stated preference studies are often overlooked in favour of revealed preference studies, which can be substantiated by real market behaviour. While stated preference (SP) studies do have the significant drawback that what consumers say they will do doesn't always match what they actually do, SP studies do have advantages over revealed preference (RP) studies. Further discussion of the limitations of stated preference studies is included in the Section 5.1.

With SP studies, the researcher has control over which variables of interest will be studied and manipulated because he or she constructs the decision context in the form of an experiment. In RP studies, a common limitation is the high degree of collinearity among variables, so that researchers cannot say with confidence the precise effect that a single variable may have on the consumer's choice to invest in the product. In this project, I am interested in evaluating the effects of various product attributes on the intangible costs perceived by the consumer. Some of these are observable; however, others are not and by controlling the choice set and attributes that a consumer sees, I can better determine what consumer preferences exist that are independent of the capital and operating costs of a product.

With mature products, such as heating systems (e.g. oil or gas furnace, electric baseboards), the market is highly competitive; therefore, there is not sufficient variability in product prices and attributes to separately derive the importance of such factors to the investment decision using RP methods. By designing the experiment to include a wide range of attribute levels, I can obtain a more robust model of consumer preferences.

The choice of heating systems has not evolved considerably in the last 20 years; heat pumps have relatively little market share so that the majority of consumers may not be aware of how such a technology is a valid alternative for them. However with a stated preference choice experiment I have the ability to include heat pumps in the choice set to determine whether the barriers to adoption are merely the upfront capital cost of this technology or if there are other intangible factors that have not been considered.

Traditional modelling perspectives

Modeling energy consumption and simulating energy policies have traditionally been based on two opposing perspectives: top-down modeling and bottom-up modeling. Top-down models use aggregate relationships between various macro-economic variables such as the Autonomous Energy Efficiency Index (AEEI) and the Elasticity of Substitution (ESUB), to estimate energy consumption and the cost of energy actions. The data used to run such models comes from historical market data and thus has been coined "behaviorally realistic" as it utilizes past market transactions as a basis for modeling consumer behaviour. Top-down models do not consider how individual technologies or consumer preferences might evolve to fit a new context. Thus it is a static representation of past market behaviour applied to uncertain future scenarios.

On the other hand, bottom-up models are based on the disaggregation of energy consumption into energy services that can be provided by a variety of technological mixes. These models assume that the substitution of technologies is feasible, as long as the level of energy service is constant. This kind of model competes different technologies based on their engineering or financial costs to provide energy services at the lowest cost. However, these models do not consider the element of intangible costs that consumers associate with particular technologies in the competition. To bridge the gap between these two modeling perspectives, hybrid models such as CIMS were developed incorporating key aspects of both traditional perspectives: technological explicitness and behavioural realism.

Hybrid models: integrating traditional perspectives

CIMS is a hybrid energy economy model that uses technology competition similar to bottom-up models to determine how market shares will be distributed among technologies for energy services. However, instead of basing competitions on engineering costs, CIMS applies a definition of life cycle cost (LCC) that differs from that of bottom-up studies by including intangible costs that represent consumer and firm preferences. LCC in CIMS represents the annualised capital costs, operating and fuel costs and intangible costs associated with particular technologies. Rather than assuming that the technology with the lowest LCC receives 100% of the market share, CIMS has a variance parameter to represent the heterogeneity in costs as seen by the population (i.e. not everyone can access the technology at the same cost and nor does everyone has the same intangible costs associated with particular technologies). The technology competition is executed using the following equations.

Equation (1) allocates the market share to a particular technology based on the relative life cycle costs and subject to the variance parameter.

$$MS_{kt} = \frac{LCC_{kt}^{-v}}{\sum_{k=1}^{z} LCC_{kt}^{-v}} \quad (1)$$

where:

MS_{kt} = Market share of k alternative in year t

LCC_{kt} = annualised life cycle cost for k alternative in year t

V = variance parameter

Equation (2) provides the formula for calculating life cycle costs in CIMS.

$$LCC_t = \left(CC \times \frac{r}{1-(1+r)^{-n}} \right) + O\&M_t + E_t \quad (2)$$

where:

CC = capital cost

r = discount rate

n = technology life span

$O\&M_t$ = operation costs in year t

E_{tj} = cost of energy form j in year t

Equation (3) represents the capital cost plus some intangible factor that is applied to the capital cost and annualized in the life cycle cost.

$$CC = FC(1+i) \quad (3)$$

where:

FC = Financial capital cost of the technology

i = intangible cost factor

Thus the "v" parameter represents the heterogeneity in the market, whereby different consumers experience different LCCs. The "r" parameter or discount rate is intended to represent time preference. And the "i" parameter represents all qualitative aspects and intangible costs or benefits associated with a technology that consumers perceive as additional costs to substitution among technologies.

The "r" parameter in the CIMS residential module is currently based on revealed preference studies, literature review and expert advice. Most revealed preference studies use data including capital costs, operating costs, available alternatives and actual market shares to estimate an implied discount rate from real market transactions. Thus the implied discount rate includes the influence of more than just time preferences with respect to cost savings; it includes consumer preferences, effects of the lack of information, split incentives, borrowing constraints and general inertia. Therefore, in revealed preference literature, estimated discount rates are much higher than one might expect a consumer to use when investing in new technology.

The "i" parameter is typically set to a default value of zero in the residential module because most data sources for CIMS do not disaggregate the financial trade-off from the intangible costs trade-off in their estimation of the implied discount rate. Therefore, it is difficult with revealed preference alone to estimate anticipated consumer gains or losses arising from future policy directions and the introduction of new technology.

The "v" parameter is difficult to measure empirically so it is a calibration parameter used to ensure a good fit between the model and the actual market shares. As we have seen in the previous section, stated preference data collection methods may be better suited to disaggregating the effects of these three parameters, “v”, “i” and “r”, especially when testing policies that create conditions that diverge significantly from the past.

1.6 Research objectives

The primary objective of this project is to improve the technology choice parameters in the CIMS model in order to explore the relative effectiveness of alternative policies for increasing energy efficient technology adoption and fuel switching in the home to meet GHG emission reduction targets. The policies under consideration include direct incentives (subsidies), strict technology regulation, and market oriented regulations (renewable portfolio standards]. Modeling consumer behaviour in response to energy efficiency policies involves significant uncertainty around the specification of the parameters to represent consumer behaviour and preferences in the model. As we have seen in the previous section, behaviour is typically modeled based on aggregated revealed preference data, which may or may not be an accurate representation of future reality. Discrete choice models are more effective at disaggregating the causal factors influencing behavioural response to policy at an individual level. The primary objective stated above can be broken into three sub-objectives:

- Better understand the attributes and preferences of residential consumers when making decisions regarding investment in heating systems or renovations that impact the efficiency of home energy consumption.
- Estimate a more behaviourally realistic intangible cost parameter.
- Incorporate this empirical behavioral data and intangible cost estimate into a model capable of predicting emission reductions for a variety of actions.

CHAPTER TWO: METHODOLOGY

2.1 Model specification

Source of data: The discrete choice experiment

The basis for any discrete choice model is the data. As we have seen, this data can be in the form of actual market transactions or revealed preferences or in the form of a survey or stated preferences. A discrete choice experiment is the latter: a sample of consumers are presented with choice sets and asked to choose the alternative that they prefer the most. Fundamental to this concept is the hypothesis that the consumer will make tradeoffs between products on the basis of the attributes that they possess rather than the product itself (Louviere, 2000). The preferences I estimate from a discrete choice experiment provide us with parameters to determine a utility function for each alternative. From the discrete choice experiment, I obtain three key elements to build the utility functions:

1. Alternative specific constant (ASC),
2. Beta coefficients for each attribute, and
3. Signs for each attribute and constant.

The ASC expresses the relative preference of one alternative compared to another. The beta coefficients provide the weighting for how much an attribute contributes to utility. The signs indicate the direction of preference (i.e. that it adds or detracts from utility). I also can calculate various test statistics (discussed in Section 3.3) that determine the significance of each element and relative fit of the models. An example of the functional form of utility for one of the alternatives in a choice experiment is presented below:

$$U_{alternativeA} = ASC_{alternativeA} - \beta(cap\ \cos t) - \beta(optg\ \cos t) + \beta(air\ quality)$$

Each alternative in the choice set has its own utility function based on the relevant combination of attributes comprising that alternative. From the utility functions, I develop a discrete choice model to predict the probability of choice.

Mathematical basis for discrete choice modelling

Consumer investment behavior for market based goods and services is richly supported by economic analysis. Economic theory provides a framework for consumer response to economic variables, pricing and marketing strategies, and macroeconomic feedbacks. While economic theory is based on qualitative hypotheses, econometrics is a mathematical, empirically derived manifestation of that theory (Gujarati, 2003). Economic theory often assumes relationships between dependent and independent variables are deterministic for the sake of simplicity, however in application, such relationships cannot be so precisely stated. Heterogeneity among consumers and in the market, as well as measurement techniques introduce error into such deterministic statements, thus econometricians are more interested in how variance in consumer behavior can be translated into an error term to test hypotheses and the predictive power of relationships.

In econometric analysis, the outcome of interest or the dependent variable, may take two different forms: quantitative or categorical (qualitative).

With respect to the first form, standard econometric methods like regression analysis are used to determine how various independent or explanatory variables affect the value of the dependent variable. The objective is to estimate the expected or mean value of the dependent variable given specific values of explanatory variables (Gujarati, 2003). Therefore, for goods that can be purchased in quantities of a continuous scale (e.g. food and beverages), the average number of goods purchased can be related to specific independent variables such as income, prices, quality, etc. When the dependent variable, "Y" is categorical or discrete (for example, Y= 1 if the consumer chooses to heat their home with a gas furnace or Y=0 if not), estimating the expected value is meaningless. In order to make sense of such a regression, the researcher needs to estimate the probability of Y=1 compared to the probability of Y=0. Probability based regression analysis is the mathematical basis for discrete choice modeling.

Understanding Random Utility Theory

The economic theory behind discrete choice modeling is the random utility theory (RUT). RUT is based on the premise that the satisfaction an individual derives from consuming a good or service can be expressed as some form of utility function. At the beginning of this section I discussed what might comprise this utility function. However, I left out elements of the utility function that cannot be readily observed and are unique to the individual. Using a statistically efficient experimental design, the researcher can attempt to determine part of the unobservable utility but a portion will remain unexplained (Louviere, cited in Bennett & Blamey, 2001). Under RUT, the unexplained utility is represented by a stochastic error term. Thus consumer utility can be expressed as follows (Train, 1986):

$U_{in} = V(z_{in}, s_n, \beta) + e_{in}$, where

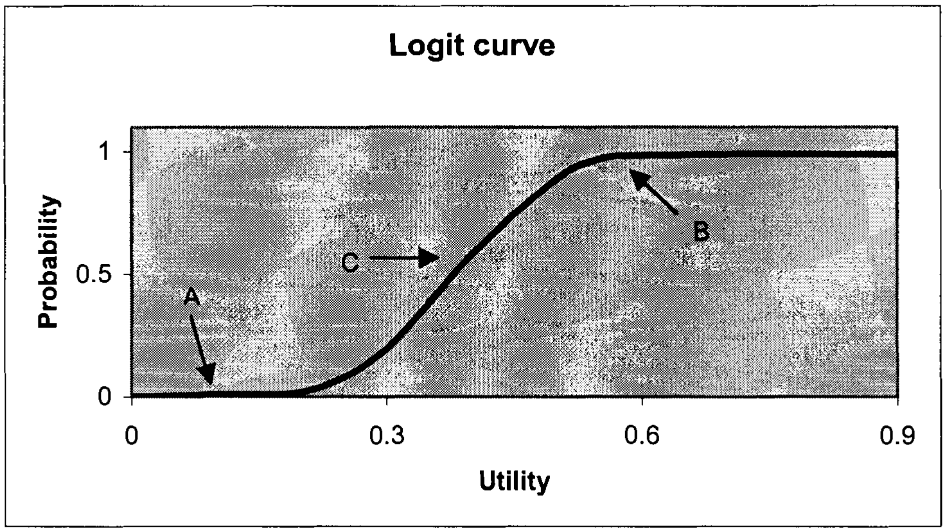
U_{in} the utility derived from alternative i in a set of J alternatives faced by consumer n,
z_{in} is the vector of observed characteristics of alternative i as faced by consumer n,
s_n is the observed characteristics of consumer n,
β is some vector of parameters, and
e_{in} is all factors and aspects of utility for alternative i faced by consumer n unknown or unobserved by the researcher.

For example, the observed characteristics of a heating system might be the purchase price, energy efficiency, and size dimensions, and the observed characteristics of the consumer might be income or education level. The unobserved portion of utility will vary across consumers and could be the perceived quality or ease of use of the heating system or the inertia to move to an unknown fuel source. Therefore, the probability of choosing an energy efficient gas furnace is the proportion of times that the researcher will observe a consumer, faced with the same alternatives and with the same value of observed utility for each alternative (such as cost or fuel savings), choosing that energy efficient gas furnace.

Selection of multinomial logit form

The unexplained portion of utility is a random or stochastic variable because it differs for every consumer. Therefore all discrete choice models are obtained by specifying a distribution for the unknown component of utility. The logit choice model assumes the unobserved utility follows an extreme value distribution (Train, 1986), as depicted in Figure 1.

Figure 1: Logit curve for unobserved utility term



The s-shaped curve means that if the utility of an alternative is very low, point A on the graph, or very high, point B on the graph, small increases in utility will not affect the probability of the alternative to be chosen. Changes in utility have the most impact on the probability of being chosen, where the utilities for various alternatives are very similar, point C on the graph. For example, if an energy efficient gas furnace and an inefficient gas furnace have close to the same utility to the consumer, then any small increase in utility for either product will change the consumer's choice. However if the efficient furnace has a very low utility then any small increases in utility will not have much effect, the inefficient furnace will continue to be preferred.

Because of the stochastic element of the utility function, consumer choice is expressed in terms of the probability of choice. The probability that the consumer will choose alternative i is expressed as (Train, 1986):

$P_{in} = e^{V_{in}} / \sum_{j \in J_n} e^{V_{jn}}$, for all i in J_n, where

e is a random variable representing the unknown characteristics, and
V_{in} is a function that depends on the observed characteristics of the alternative and of the consumer and a vector of estimated parameters, and
J_n indexes the choices available to the consumer.

2.2 Understanding discrete choice experiments

Choice experiments provide the researcher with an experimental design and survey tool to elicit stated preferences from a sample of consumers. The choice question can be framed in two different ways. A conjoint choice experiment asks the respondent to rank a number of alternatives in order of preference. A discrete choice experiment asks the respondent to choose the most preferred option among several alternatives. The choice is discrete in that the consumer can only choose one alternative from a choice set. For example, for this project I have assumed that a consumer can only invest in one primary heating system. Thus, respondents are asked to choose one heating system from four choices. While I acknowledge that a home can have several different heating technologies employed, generally one source is easily identified as the primary heating method from four choices.

The alternatives in the choice set should correspond to the alternatives that the consumer would normally see in the marketplace. Choice experiments assume that consumers invest in a bundle of attributes for a particular product, not the product itself, therefore each alternative is defined by a number of attributes. An attribute can be quantifiable (e.g. capital cost, operating cost, efficiency) or qualitative (e.g. heating air quality, responsiveness, noisiness). The researcher sets the levels of each attribute to cover a wide enough range to be able to establish the tradeoffs that consumers make when deciding among alternatives (e.g. for a quantifiable attribute like capital cost - different price levels and for a qualitative attribute - poor, medium and high air quality). The researcher can use generic alternatives or labelled alternatives. Generic alternatives would be shown to the respondent as Option A, Option B, Option C, all of which would be heating systems, and one of the attributes might be fuel source. Labelled alternatives would be shown to the respondent as Natural gas furnace, Wood fireplace, Heat pump, etc.

2.3 Critical choices in residential sector

Applying this methodology to the problem of adoption of energy efficient technology and fuel emission reductions in the home, I could explore any number of energy consuming durables. From a review of the literature, researchers have often chosen appliances as the purchase choice (Hausman, 1979, Hutton & Wilkie, 1980, Nanduri, et al, 2002). As most energy is consumed by a household through the heating or cooling of a home, the efficiency of the shell of the household and of the heating system itself represent the areas of greatest potential for GHG emission reductions. Thus two discrete choice experiments were designed around the choice of the principal home heating system and the choice of home renovation with and without energy efficiency improvements. This project presented an opportunity to compare studies on appliance choice to other energy choices such as renovations and heating systems. Energy efficiency measures such as improved insulation and high efficiency heating systems do not have the visual or ancillary service characteristics of appliances and, therefore, behavioural parameters may be quite different from those derived from appliance choice.

2.4 Telephone presurvey – sampling criteria & selection

A questionnaire was sent by mail to a sample of 950 homeowners of single- family detached homes across Canada. To improve the response rate and to screen for individuals that met the recruitment criteria, residential consumers were randomly contacted by telephone prior to the mail out by MarkTrend, a marketing and research consulting company. The telephone presurvey was used to select homeowners of single-family detached dwellings. Additional information was collected concerning the primary heating system used by the homeowner and the annual heating costs for the home. A copy of the telephone presurvey is included in Appendix A.

Once agreement to participate in the survey was obtained, a formal cover letter and survey were mailed to the respondents. To encourage individuals to return the survey, a one-dollar coin was attached to the cover letter as a token of appreciation for their time. In addition, respondents were told that for every returned survey, one dollar would be donated to UNICEF. A reminder postcard was sent out two weeks after the initial mailing.

In order to provide representative parameters for CIMS, a national sample was required. Residential consumers were contacted proportionate to the population in each of the following five regions: British Columbia (BC), Prairie provinces (PR, including Alberta, Saskatchewan and Manitoba), Ontario (ON), Quebec (QB) and the Atlantic provinces (AT, including Newfoundland, Nova Scotia, New Brunswick and Prince Edward Island). These regions roughly correspond to the regional breakdown in CIMS. Both rural and urban centres were included in the sample to ensure that all Canadian homeowners were represented, including areas that may not be well serviced by energy providers.

2.5 *Questionnaire design*

The questionnaire was divided into five sections (a copy of the questionnaire is included in Appendix B):

Part 1: General home characteristics & current level of energy efficiency
Part 2: Renovation choice experiment
Part 3: Heating system choice experiment
Part 4: Motivations for investment in energy efficiency
Part 5: Demographic information

The purpose of the first part of the survey was to act as a warm-up for the respondents as well as provide basic information about the age and size of the home, number of residents living in the home and the level of energy efficiency of the household. The questions are relatively easy to answer and introduce the topic of home energy efficiency.

Diffusion of innovation theory suggests that if consumers are not aware of a problem with a current technology, they have no incentive to search for alternatives (Rogers, 1995); therefore, several questions were asked to determine the level of awareness of the respondent with respect to the energy efficiency of their households.

The second and third parts of the survey represent the choice experiments, which are described in detail in Section 2.6.

The fourth part of the survey focused on questions regarding key factors in the respondent's decision-making process. One question asked the respondent to rate the importance of various factors in the purchasing decision of a new heating system. These results provide a basis to determine what qualitative attributes might be contributing to the intangible costs associated with the replacement of a heating system. The next question attempted to evaluate the influence of market share of new technologies on investment behaviour. For new technologies, there is often some threshold of market share, below which diffusion of the technology is slow and above which adoption increases at a rapid rate as consumers observe others benefiting from the technology. In the final question, respondents were asked to express their degree of support for various home energy policies to encourage investment in energy efficiency.

2.6 Alternatives, attributes & levels

The specific alternatives, attributes and levels in the discrete choice experiments were selected to be consistent with existing parameters in CIMS. I next describe the selection of attributes and levels in detail for each of the choice experiments.

Home Renovation Choice Experiment

In this choice experiment, the respondent was asked to assume that they were undertaking a renovation to their home involving upgrades to the structural characteristics of the home. Respondents were asked to choose between a renovation that did not include energy efficiency retrofits and a renovation that did. Energy efficiency retrofits were defined for the respondent as improved insulation in the walls, ceiling and floors, weather stripping of the doors, and replacement of single paned windows with double or triple paned windows. Each respondent was asked to answer four choice questions.

Constraints related to the space available in the survey and the simplicity of the experimental design discussed in Section 2.7, limited the number of attributes that were included in this experiment. To ensure that a discount rate could be estimated, both capital cost (i.e. the cost of the renovation upfront) and operating costs (i.e. the annual heating costs) were included as attributes of each alternative. To simulate subsidy policies, a subsidy attribute was included for the energy efficient alternative, taking the levels of $0, $500 or $1000. Finally a discrete variable, the comfort level in terms of low or high air quality within the home was included as an attribute hypothesized to contribute to the intangible cost. The respondent was informed that air quality comprised ventilation, humidity and temperature within the home.

Again constrained by the experimental design, the attributes were assigned only 2 levels each. The capital cost of the renovation was based on the results from the *Commercial/Institutional and Residential Sector Cost Curves: Buildings Table Report* (Marbek Resource Consultants, 1999). The costs from this report were rounded to the nearest thousand to ensure the respondents could easily calculate payback period or discounted cash flows. The levels from the survey are shown in Table 1.

Table 1: Capital cost levels for renovation experiment

Renovation:		BC	PR	ON	QB	AT
Energy efficient	*Level 1*	$ 12,000	$ 10,000	$ 13,000	$ 13,000	$ 14,000
	Level -1	$ 9,000	$ 7,500	$ 10,000	$ 10,000	$ 11,000
General	*Level 1*	$ 7,500	$ 6,000	$ 7,500	$ 7,500	$ 9,000
	Level -1	$ 6,000	$ 5,000	$ 6,000	$ 6,000	$ 7,000

The second level (*Level –1*) for the capital cost of the energy efficient renovation was the full cost less 25% (rounded to the nearest 500). The current capital cost of an energy efficiency renovation in the market today was considered to be the maximum amount that an individual would be willing to pay for energy retrofits.

The operating or annual heating costs were customized for each individual based on their current annual heating costs within the ranges indicated below:

Table 2: Customization of annual heating costs attribute

Actual annual heating costs	Assumed heating cost
x < $1000	800
$1001 < x < $1500	1200
$1501 < x < $2000	1800
x > $2001	2200

In the telephone pre-survey, the respondents were asked the amount of their most recent heating bill, as well as the relevant billing period so that actual annual heating costs could be calculated. The first level for the standard renovation operating cost attribute was the customized cost, with the second level being 30% higher. The first level for the energy efficient renovation was

15% lower than the customized cost as an improvement in energy efficiency to the Model National Energy Code for Houses (MNECH) standard represents approximately 12% savings in energy costs (Marbek, 1999). MNECH is the minimum energy efficiency requirement for new housing. The second level for the energy efficient renovation was 25% lower than the customized cost representing the savings derived from renovations to the R2000 standards (Marbek, 1999). R2000 is a technical performance standard for more energy efficient homes that is a higher standard than the minimum building codes.

Home Heating System Choice Experiment

In this choice experiment the respondent was asked to assume that they needed to replace their existing heating system. They were asked to choose between several heating systems assuming that all fuel types were available in the region:

- Standard efficiency gas furnace/boiler,
- High efficiency gas furnace/boiler,
- Electric baseboards,
- Heat pump, or
- Standard efficiency oil furnace/boiler (only shown for those respondents who are currently using oil).

The first four choices were the standard choice set for most respondents. However, if the respondent was currently heating his/her home with oil, oil was presented in the choice set to make the choice set more realistic. A random number was used to determine which of the other heating system choices the oil choice would replace for each question in the experiment.

Although the choice set did not include all possible heating options, the principal heating sources were available. Alternatives such as wood stoves, electric furnaces and other energy sources represent only 5%, 2% and 9% respectively of principal household energy sources, according to NRCan's *1997 Survey of Household Energy Use*. The choice task would have been unnecessarily complicated if all energy sources were included given the relative insignificance of these energy sources. Although heat pumps had only 5% of the market share in 1997, it was included as alternative because it is a high efficiency, low GHG emission energy source that has the potential to gain market share with the implementation of the Kyoto Protocol.

Again, the number and level of attributes for the heating system choice set were constrained by the experimental design. To ensure that a discount rate could be estimated, both capital cost (the purchase price of the heating system) and annual operating costs, were included as attributes of each alternative.

Capital costs of the various heating systems were based on the *Buildings Table Report* (Marbek, 1999) supplemented by inquiries at a local heating system retailer. The levels are outlined in Table 3. The capital costs for all heating systems but the heat pump were the same across Canada. The variation in heat pumps is based on the difference in how the heat pump is installed depending on the geographic and climatic characteristics.

With the exception of the heat pump, annual operating costs for the heating systems were calculated using the EnerGuide heating cost calculator, assuming the following heating loads: British Columbia = 120 GJ, Ontario = 140 GJ, Prairies = 160 GJ, Quebec = 140 GJ and Atlantic = 130 GJ. The levels for the operating costs are included in Table 3.

Table 3: Capital and operating costs for heating choice experiment

		BC	ON	QB	PR	AT
Capital cost						
Standard gas/oil	*Level -1*	2,200	2,200	2,200	2,200	2,200
	Level 1	2,700	2,700	2,700	2,700	2,700
High efficiency gas	*Level -1*	3,200	3,200	3,200	3,200	3,200
	Level 1	4,000	4,000	4,000	4,000	4,000
Electric	*Level -1*	1,400	1,400	1,400	1,400	1,400
	Level 1	2,000	2,000	2,000	2,000	2,000
Heat pump	*Level -1*	6,000	7,000	8,000	7,000	7,000
	Level 1	13,000	14,000	15,000	14,000	14,000
Operating costs		**BC**	**ON**	**QB**	**PR**	**AT**
Standard gas/oil	*Level -1*	1,000	800	600	900	1,200
	Level 1	1,400	1,200	900	1,300	1,700
High efficiency gas	*Level -1*	800	700	500	800	1,100
	Level 1	1,200	1,000	700	1,100	1,500
Electric	*Level -1*	1,300	1,600	1,500	2,000	2,000
	Level 1	1,900	2,300	2,200	2,900	2,800
Heat pump	*Level -1*	200	400	300	400	300
	Level 1	300	500	400	500	400

To simulate subsidy policies, a subsidy attribute was included for the high efficiency alternatives: high efficiency natural gas and the heat pump. Subsidies for the heating system were assigned levels of $0 or $300 for a high efficiency gas furnace, based on recent rebates offered by gas suppliers for the purchase of high efficiency furnaces. Subsidies for heat pumps were assigned levels of $0 or $1000 based on an arbitrary maximum subsidy a retailer or the government would likely be willing to offer.

Finally the responsiveness of the heating system was included as a discrete variable that might contribute to the intangible cost. Responsiveness was described as how long the system takes to get the home up to the desired temperature. As consumers turn the heat up when they arrive home from work or school and expect an immediate response, the responsiveness of the system was hypothesized to be an important attribute of a heating system based on the results from the pilot survey. Furthermore the responsiveness was perceived by the consumer to vary according to the efficiency of the system such that high efficiency systems are more responsive. Air quality was considered as an attribute but rejected, as different heating systems were not considered to vary in terms of indoor air quality. The air quality attribute better related to the issue of home insulation. Initially the responsiveness was coded as slow or fast, however in the pilot survey, respondents requested more precise information regarding the responsiveness, therefore the attribute was coded as "Within ½ hour" or "Within 1 hour".

2.7 Experimental design

Any choice experiment represents only a sample of choice sets from a much larger population of choices (Louviere, 2001, cited in Bennett & Blamey). The researcher needs some method of selection from that sample of choice sets. Compared to random selection, factorial designs maximize the efficiency of the experimental design to ensure the quality of the estimated parameters and model form. Complete factorial designs examine all possible combinations of each level of the attributes or factors of interest. Complete factorials have the advantage of calculating interaction effects as well as main effects, reducing the risk of false conclusions (Montgomery, 1991). With complete factorials, the effects of a factor can be estimated over a range of values for the other factors, increasing the scope of analysis (Montgomery, 1991). Unfortunately, as the number of attributes of interest increase, the size of the factorial design increases exponentially, which increases the sample size required for a statistically significant model beyond what is feasible for this project and most research. Therefore, more complex studies require a smaller design that retains most advantages of a complete factorial design. If higher order interaction effects are assumed to be negligible, then main effects and low order interactions can be estimated from fractional factorial designs (Montgomery, 1991).

For this project, the 2^{k-p} fractional factorial design was used for both experiments, where k is the number of attributes in the choice experiment and p is the number of independent generators (i.e. the statistically derived relations that define the design of the factorial) (Montgomery, 1991). The "2" indicates that each attribute has two levels. The two-level fractional factorial was chosen because the experimental design is relatively simple to work with. In comparison, three level fractional factorials may allow the researcher to detect a non-linear functional form of utility; however, they require complex experimental designs that are beyond the scope of this project.

Home Renovation Choice Experiment

For the home renovation choice experiment, there were 2 alternatives (a home renovation with or without energy retrofits) with 3 attributes each and 2 levels for each attribute: capital cost (high, low), operating cost (high, low) and comfort level (high, low). The subsidy attribute had 3 levels ($0, $500 and $1000).

A 2^{8-4}_{IV} fractional factorial design was used for this choice experiment. The Roman numeral subscript indicates the resolution (i.e. the degree to which the main effects and interaction effects can be separately identified) of the design. From a resolution IV design the main effects can be estimated as well as some two-factor interactions (Montgomery, 1991). There were 16 different choice sets, of which, any one individual only saw four.

Heating System Choice Experiment

For the heating system choice experiment, there were 5 alternatives with 3 attributes each and 2 levels for each attribute: capital cost (high, low), operating cost (high, low) and responsiveness (slow, fast). In addition there were 2 subsidy attributes with 2 levels (none or $300 subsidy) for each of the high efficiency gas and heat pump alternatives. A 2^{15-11}_{III} fractional factorial design was used for this choice experiment. As this was only a resolution III design, only the main effects can be estimated for this experiment. There were 32 different choice sets, of which, any one individual only saw four.

CHAPTER THREE: SURVEY RESULTS, ANALYSIS & DISCUSSION

3.1 Demographics of the sample

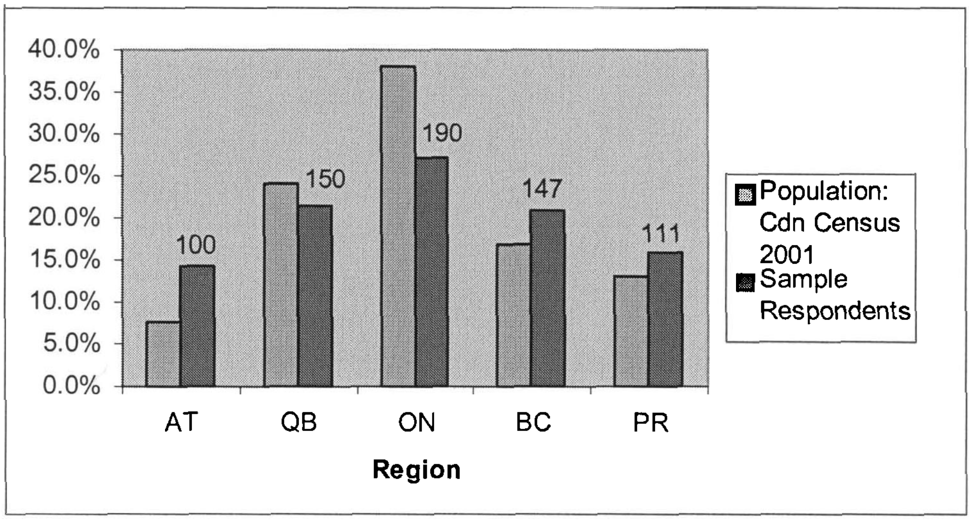
Of the 950 questionnaires sent out, 698 were returned, representing an overall response rate of 73%. The high response rate is attributed to the pre-survey telephone recruitment. Models of the choice experiments were estimated from data sets that excluded non-response answers. 70 surveys were missing responses to the experiment questions for the renovation choice experiment and only 39 surveys were missing responses for the heating system choice experiment. After removing incomplete or incorrectly completed surveys, 625 valid returned surveys remained for a qualified response rate of 66 percent.

Table 4: Sample response rates

Total surveys sent out	950	100%
Total returned surveys	698	73%
Less: Blank surveys returned	3	
Less: Surveys with incomplete answers to the discrete choice experiments	39 -70	
Valid returned surveys	625 - 656	66-69%

From the regional segmentation of the returned surveys shown in Figure 2, the Atlantic, Prairie, and British Columbia regions were over represented in my sample compared to the national population distribution. Ontario and Quebec were under represented.

Figure 2: Comparison of respondents to population by region



In an attempt to ensure that there were sufficient respondents by region to estimate a regional discrete choice model, the minimum survey contacts for each region obtained by the telephone company were 150[1]. Therefore the full sample distribution was consistent with the respondent distribution (see Table 5).

Table 5: Comparison of respondents to sample by region

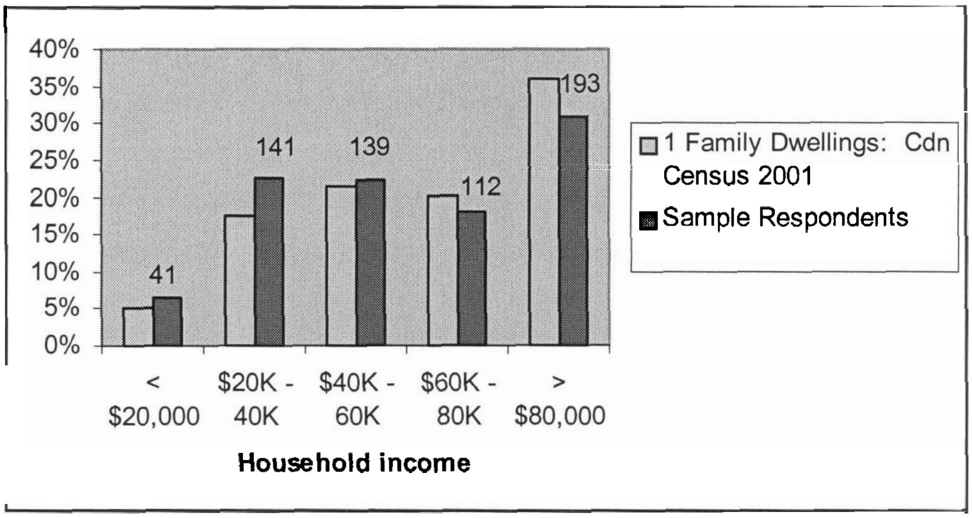
	Survey sample		Actual Respondents	
AT	137	14.3%	100	14.3%
QB	200	20.9%	150	21.5%
ON	263	27.5%	190	27.2%
BC	202	21.2%	147	21.1%
PR	153	16.0%	111	15.9%
Total	955	100.0%	698	100.0%

Respondents were equally represented by gender with 45% women and 47% men and 8% no answer. Higher income groups were over represented compared to national population standards due to the filtering criteria of home

[1] This minimum requirement was obtained for each region with the exception of the Atlantic region, where only 137 potential respondents were obtained.

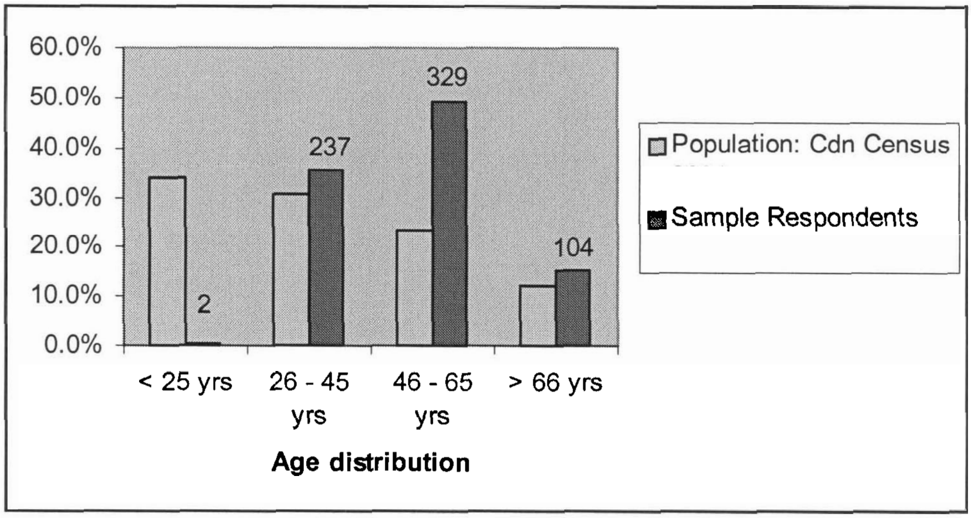
ownership of a single-family detached dwelling. Owners of single-family dwellings are more affluent that the average consumer in Canada. When compared to the population of single-family dwellings, the household income levels were relatively proportionate as can be seen in Figure 3 below. There were 72 respondents that refused to answer the question.

Figure 3: Comparison to population of single-family dwellings by income



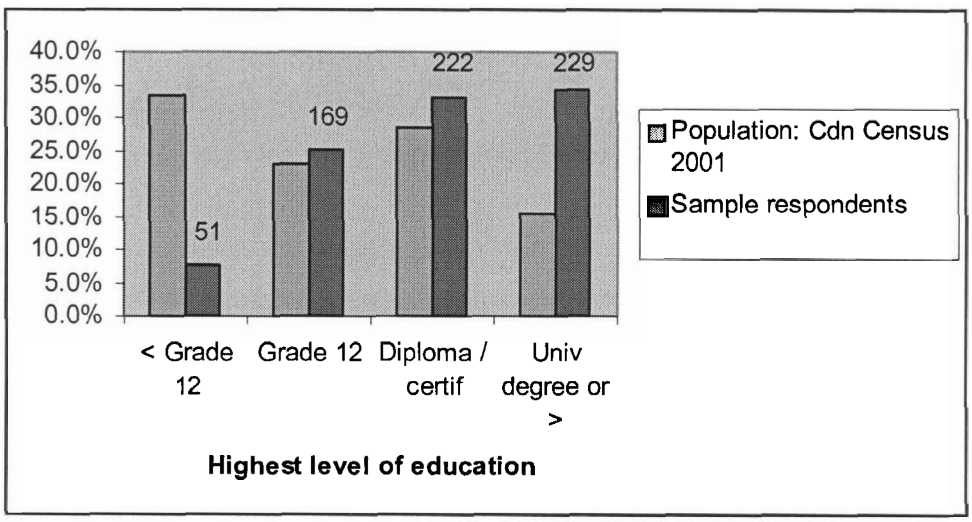
The age of the respondent is skewed to an older segment of the population because the screening criteria for the telephone presurvey required single- family homeowners. This homeowner group is middle aged to those in early retirement indicated by the trend in Figure 4 below. This trend is reasonable given that young homebuyers and retired homebuyers would be more representative of the condominium and townhome homeowner segments.

Figure 4: Comparison of respondents to population by age distribution



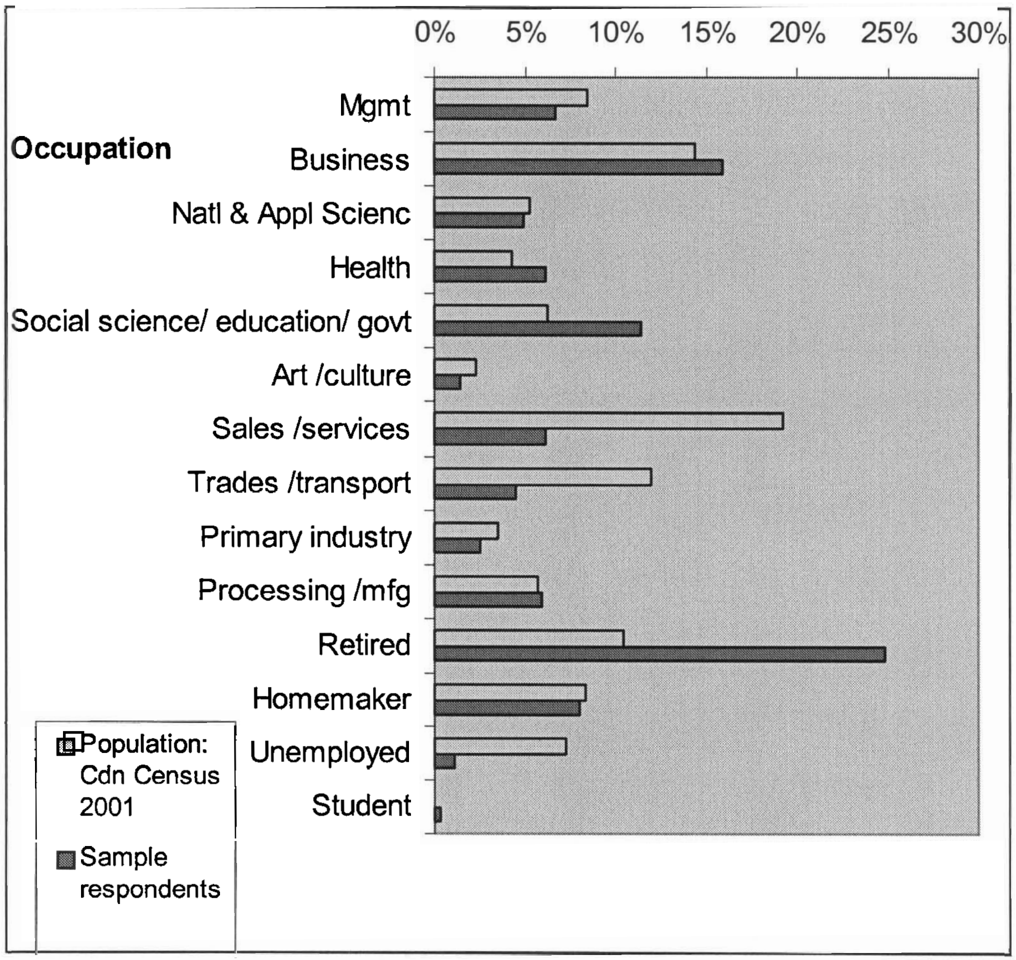
Respondents were well educated with over 65% of the sample with post secondary education, which again, is likely correlated with home ownership and income level. In comparison to national education levels, individuals with less than a high school level of education were underrepresented in the survey sample largely because the sample was restricted to respondents older than 18 and who owned a single-family dwelling. There were 21 respondents who did not provide an answer to this question.

Figure 5: Comparison to population by level of education



The occupational status recorded by the respondents were coded according to the National Occupational Classification for Statistics, with additional categories created for retired respondents, homemakers, unemployed individuals and students. This was compared to data available on the national population as is seen in Figure 6.

Figure 6: Comparison to population by occupation



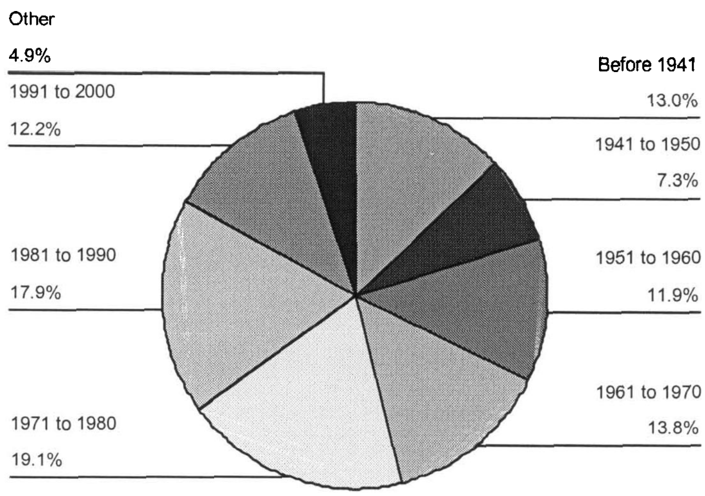
Most respondents were proportionate to the population in terms of occupational classification with the exception that a disproportionate number of retired individuals were in the sample and certain categories such as sales/service and trades/transport were underrepresented. As the telephone survey took place from 8am to 8pm, it is reasonable to expect that a larger number of respondents were working when first contact was made; therefore, the sampling method produced a bias towards retired persons and homemakers. The reason the unemployed and student categories were so low in the sample is largely due to the fact that many of these individuals were filtered from my sample with the homeownership question.

3.2 Survey results

Home characteristics & level of energy efficiency

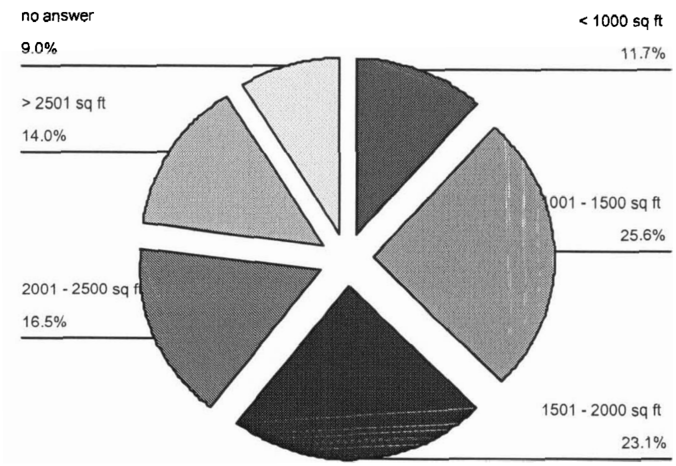
The year of construction of the home was relatively evenly distributed across respondents as can be seen below. Although the categories are slightly different, the vintage of the home for this sample is similar to the distribution reported in NRCan's *1997 Survey of Household Energy Use.*

Figure 7: Year of construction of sample home



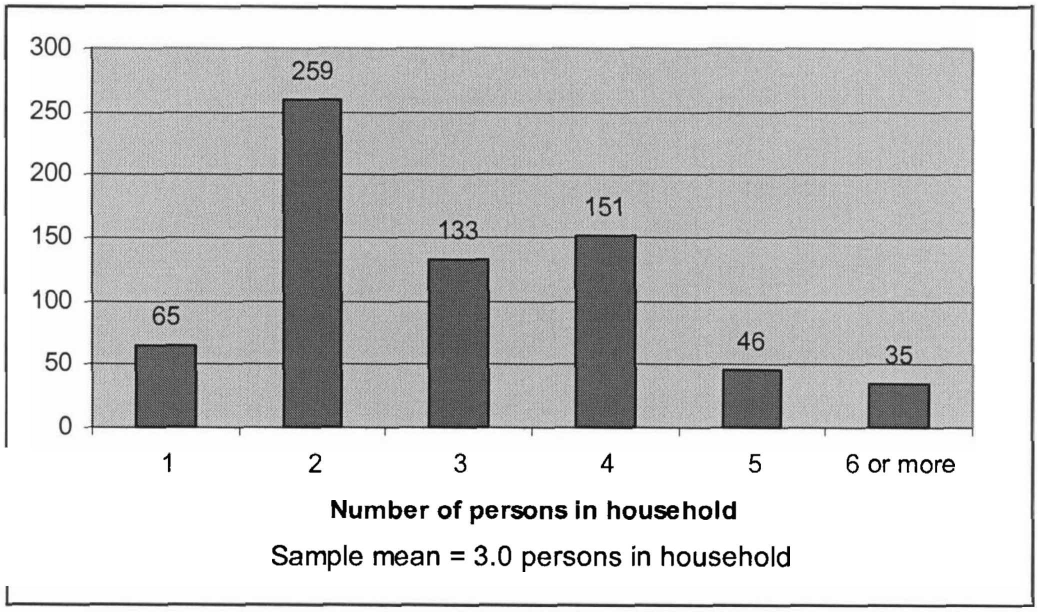
The survey sample has a greater average heated living area, 1875 square feet compared to 1405 square feet reported in NRCan's *1997 Survey of Household Energy Use.* As this sample only includes single detached homes, it reasonable to assume that the heated area would be larger on average compared to the total housing stock in Canada. The distribution of the heated living area is shown below.

Figure 8: Heated living area of sample home



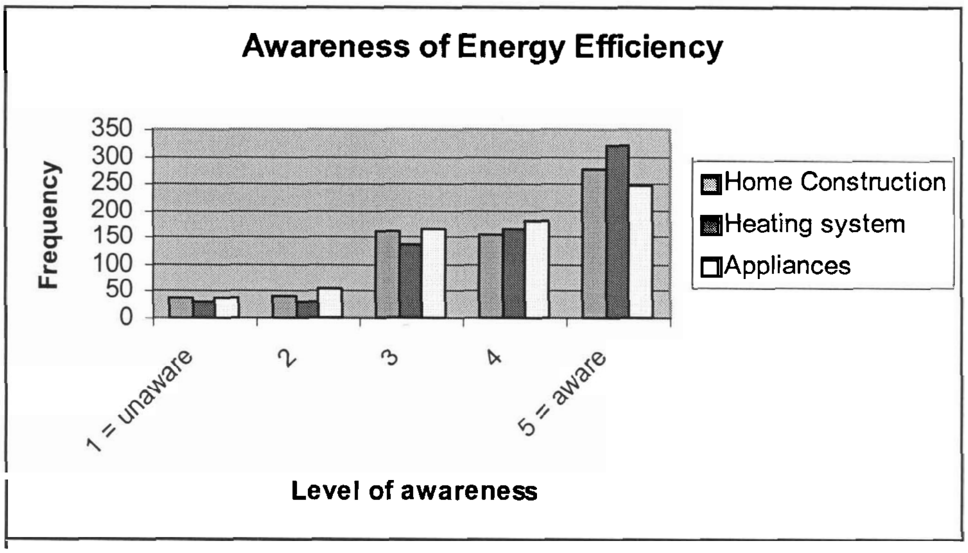
The size of the household, in terms of the number of persons residing in the sample home, is proportionate to the national population. The mean for the national population is 3.1 persons compared to a sample mean of 3.0 (Canada Census 2001). The sample distribution for the number of persons per household is presented in Figure 9.

Figure 9: Distribution of sample number of persons per household



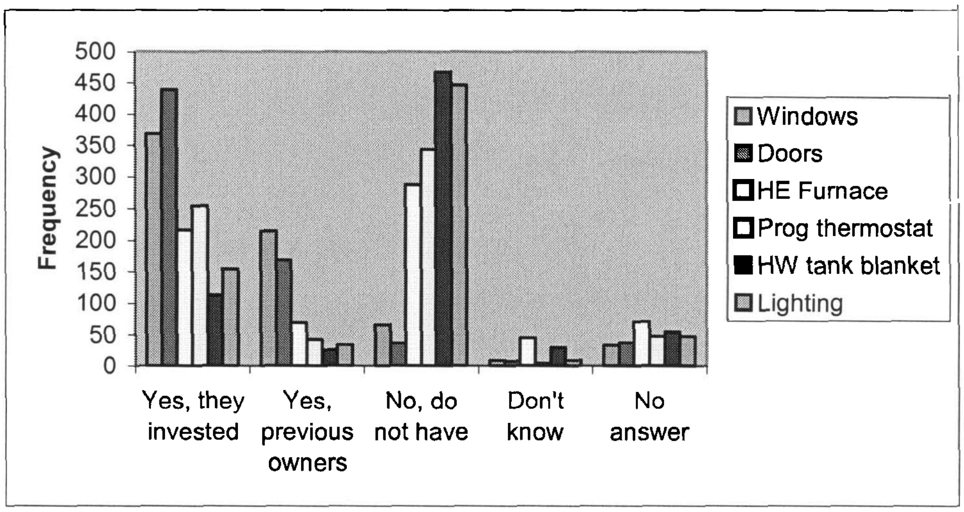
When asked to report on their level of awareness of the energy efficiency of the home construction, heating system and appliances for their household, the majority of respondents rated their awareness as high, with the heating system efficiency being what they were most familiar with.

Figure 10: Level of awareness of home energy efficiency



The majority of respondents had invested in double or triple paned windows (53%) and weather stripping around the doors (63%). Less than 10% of households in the sample did not have such features at all. In comparison, almost 50% of households sampled did not have high efficiency furnaces or programmable thermostats, 67% of households sampled did not have hot water tank blankets and 64% of households sampled did not have at least 25% of fluorescent lighting in their home.

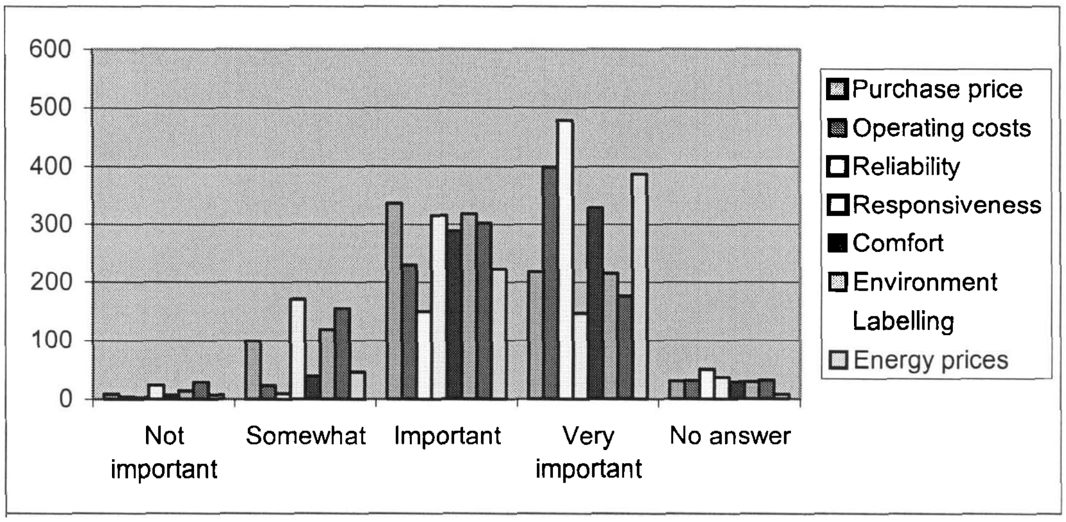
Figure 11: Investment in energy efficient features in sample home



Importance of attributes, dynamic preferences and policy preferences

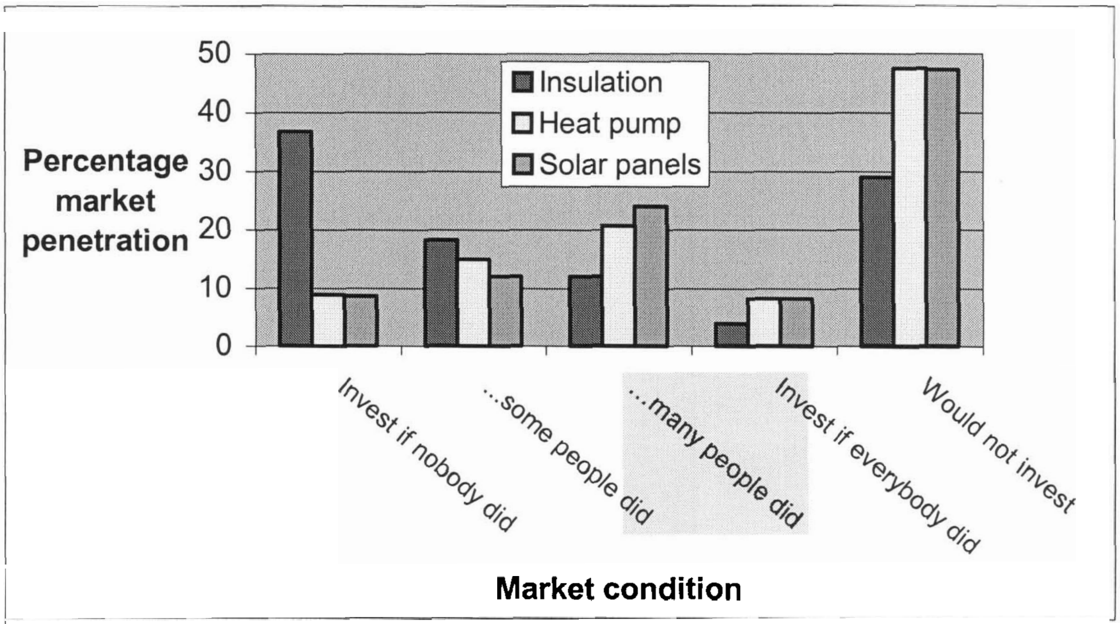
When purchasing a new heating system, over 68% of respondents considered reliability to be very important. Although this attribute is very important to consumers, suggesting that reliability may have been a better discrete variable to represent intangible costs in the heating choice experiment, it would be difficult to determine whether or not one heating energy source over another would be more or less reliable. Consumers perceive reliability based on their past experience with heating systems. It would be interesting to assess how consumers rate each heating system based on these attributes. It appears that operating costs of heating systems are more important than the purchase price, as 57% of respondents rated operating costs as very important compared to 31% who rated purchase price as very important, although the degree to which this is true is further explained by calculating the implicit discount rate. Unfortunately there was little variance between many of the remaining factors.

Figure 12: Importance of heating system attributes



In an attempt to determine how the market share of technologies might influence the consumer decision to invest, the respondents were asked at what point (based on the number of people that had already invested and successfully cut energy costs) they would be willing to invest in three energy efficient technologies: insulation, heat pumps and solar panels. Unfortunately, almost half of the respondents did not understand the question and had to be excluded from the analysis. The distribution for the remaining 383 respondents is shown in Figure 13.

Figure 13: Market penetration of energy retrofits



In terms of energy policies, respondents showed little variation between policies. With the exception of raising energy prices, respondents were largely in favor of each policy. The distribution of support for energy policies are shown in Figure 14 and 15. A strong level of support was for regulatory energy policies thus suggesting that consumers may not lose as much utility as originally thought by constraining the choice set.

Figure 14: Level of support for regulatory and informational energy policies

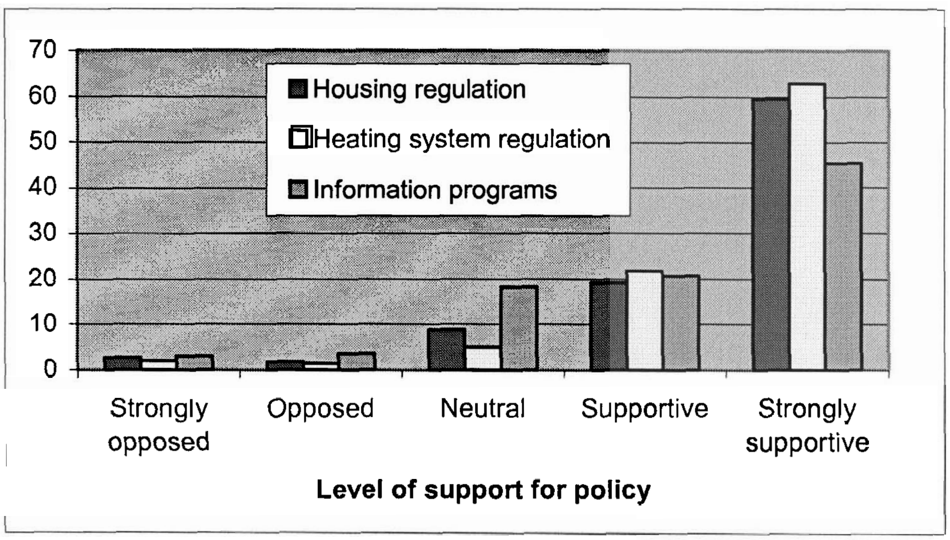
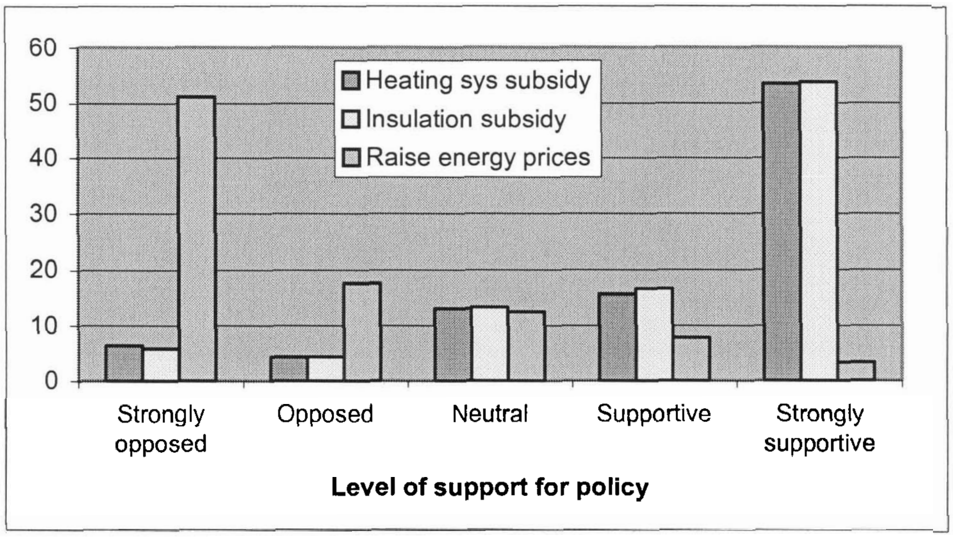


Figure 15: Level of support for subsidy and pricing policies



3.3 Model estimation

Renovation choice experiment results

Table 6 shows the part-worth or marginal utilities for each attribute and alternative specific constant (ASC) for the renovation choice experiment. Attribute coefficients were estimated using the binomial logit model in econometrics software, Limdep 7.0. The model was estimated using 2499 choice questions from all surveys that answered the renovation choice experiment questions correctly. Given the limitation of two levels or data points for each attribute, I can only estimate a linear relationship between the attributes and utility. While a linear relationship may be a reasonable assumption for the cost coefficients in the range of values of interest to policy-makers, further research is required to test the functional form for the discrete variable of air quality in the home. As shown in Table 6 below, all of the coefficients in this model are statistically significant at the 95% confidence level therefore all attributes were retained in the final model.

Table 6: Coefficient and constant estimates for renovation choice model

	Full sample	
Attribute name	Coefficient	t stat*
Capital cost	-0.00025	-9.12
Subsidy	0.00041	3.49
Annual Heating cost	-0.00122	-7.62
Comfort Level	1.55905	19.44
Standard Reno Constant	-0.74909	-5.18
Efficient Reno Constant	referent	
Discount rate	20.79%	
L(0)	-1,732	
L(b)	-1,381	
L(c)	-1689	
Q = x^2 with 16 d.o.f.	702	
Qc = x^2 with 16 d.o.f.	616	
n	625	

*a *t*-stat. of absolute value >1.96 = 95% confidence level;
a t-stat. of absolute value >1.64 = 90% confidence level

The signs for the attributes, with the exception of the alternative specific constant, are consistent with expectations. Higher capital cost and annual heating costs reduce the consumer utility in a particular choice, whereas the presence of subsidies increases the consumer utility. The comfort level attribute has a positive sign and is highly significant, indicating that increased air quality increases consumer utility. The negative sign of the alternative specific constant indicates that with this model the Energy Efficient Renovation or base of reference[2] is preferred to the Standard Renovation without energy retrofits. Although it is reasonable that consumers would see energy efficiency as a desirable attribute, I did not expect the preference to be a driving factor in consumer choice. Obviously consumers perceive additional benefits to energy

[2] The term referent in this case means that it is used by the model as a base of reference from which to compare the preference of one alternative to another alternative. It makes no difference which alternative is the referent alternative as the ASC will measure the differential between the two alternatives.

efficient homes that are not visible to the observer. Consumers may associate energy efficiency with higher quality.

The likelihood ratio test statistic (denoted "Q" in Table 6) is used to assess the explanatory power of the model, with a larger value indicating higher explanatory power. The likelihood ratio test statistic is calculated using the log likelihood values (denoted "L" in Table 6) for various different hypotheses:

- Hypothesis 1: an equal probability of choice such that all coefficients are zero (Hausman, 1979):

$$Q = -2(L[0] - L[b]) \text{ is } \chi^2 \text{ distributed with } k \text{ degrees of freedom},$$

- Hypothesis 2: all coefficients except the alternative-specific constants are zero:

$$Q = -2(L[c] - L[b]) \text{ is } \chi^2 \text{ distributed with } (k - J + 1) \text{ degrees of freedom}$$

Given the high values of the log likelihoods, it is not surprising that the first hypothesis can be rejected at the 95% confidence level. The rejection of the second hypothesis at the 95% confidence level suggests that attribute coefficients do add significant explanatory power to the model.

Heating system choice experiment results

Table 7 shows the part-worth (marginal) utilities for each attribute and alternative specific constant (ASC) for the full sample and a segmentation that excludes oil from the choice set. The multinomial logit model for this choice experiment was also estimated using econometrics software Limdep 7.0. The model was estimated using 2625 choice questions from all respondents that answered the heating system choice experiment questions correctly. Given the limitation of two levels or data points for each attribute, once again, I can only estimate a linear relationship between the attributes and utility. Only those respondents who were currently heating their home with oil saw oil in the choice set. Therefore, a second model was run excluding the oil furnace/boiler alternative in an attempt to strip out the domination of that alternative from the rest of the sample.

All attributes are significant at the 95% confidence level, with the exception of the responsiveness attribute in the first model. Although this attribute was not quite significant even at the 90% confidence interval, when I estimated the model without the responsiveness attribute, there were no significant changes in the coefficients and the explanatory power remained the same. Therefore, the responsiveness attribute was retained in the final model to be used in simulations in Section 4.2. All the alternative specific constants in the full model are significant at the 95% confidence level, with the exception of the high efficiency gas constant, which is not significantly different from the oil constant.

Table 7: Coefficient and constant estimates for heating system choice model

	Model 1: Full sample		***Model 2: Excluding oil***	
Attribute name	Coefficient	t stat*	Coefficient	t stat*
Gross capital cost	-0.00015	-11.23	-0.00016	-10.31
Subsidy	0.00024	2.68	0.00024	2.41
Operating cost	-0.00171	-15.55	-0.00190	-13.60
Responsiveness	-0.07902	-1.57	-0.13590	-2.28
Standard Eff Gas Constant	-0.85257	-9.31	-0.30923	-1.84
High Eff Gas Constant	-0.04850	-0.54	0.53067	3.86
Electric Constant	-0.52659	-3.81	0.02308	0.09
Heat pump Constant	-0.46242	-2.88	referent	
Oil Constant	referent			
Discount rate	8.78%		8.36%	
L(0)	- 4,224		- 2,635	
L(b)	- 2,987		- 2,084	
L(c)	n/a		- 2,252	
Q = x^2	2,474	with 34 d.o.f.	1,102	with 28 d.o.f.
Qc = x^2	n/a		336	
?2	0.293		0.209	
n	656		475	

*a *t*-stat. of absolute value >1.96 = 95% confidence level;
a t-stat. of absolute value >1.64 = 90% confidence level

For both models the signs for the attributes are consistent with expectations. Higher capital cost and operating costs reduces the consumer utility in a particular choice, whereas the presence of subsidies increases the consumer utility. The sign on the responsiveness attribute indicates that increased time for the heating system to reach the desired temperature decreases consumer utility.

From the full model results, the negative sign on the alternative specific constants for each heating system indicates that they are less preferred to oil, although the parameter for high efficiency gas is not significant. This result can be attributed to the strong preference of those respondents who currently have oil, to stay with oil. From the sample of respondents who did not have oil in the choice set, high efficiency gas is preferred over heat pumps. At the 90% confidence level, standard efficiency gas is less preferred to heat pumps. The preference for electric baseboards is not significantly different from heat pumps.

The magnitude of the coefficients for the capital cost, subsidy and operating cost are similar across both models indicating that a high degree of confidence can be placed on these values. However the responsiveness attribute in the first model is significantly different at the 95% confidence interval from the responsiveness attribute in the second model. This indicates that variable is heterogeneous across the sample population.

The high values of the likelihood ratio test statistic indicate that both models have significant explanatory power, with the full sample model having relatively more explanatory power than the model that excludes the oil alternative. The goodness of fit test, similar to the R^2 test in regression analysis, is useful when comparing different specifications of models to determine the tradeoff between degrees of freedom and additional explanatory power. With discrete choice experiments the test statistic is as follows (Ben-Akiva and Lerman, 1985):

$$\rho^2 = 1 - (L(b) / L(0).$$

The rho-squared test statistic is often quite low for discrete choice experiments, although used as a comparative statistic, the higher value of the first model indicates more explanatory power than the second model. Therefore, the first model parameters are used for the simulations of the national sample in Section 4.2 as oil furnaces are a heating technology in CIMS and have important implications for GHG emissions.

3.4 Discussion of Discrete Choice Models

Renovation choice model: Discussion

Time Preferences: Estimating a discount rate for renovation choice

With the estimates of coefficients for capital cost and operating cost from Table 6, I calculate a discount rate to determine the tradeoff between operating costs and the initial purchase price for the study sample. Assuming an infinite life and no scrap value at the end of the life of the renovation energy retrofits, the discount rate can also be approximated from the ratio of the capital cost coefficient to the operating cost coefficient. Using the results from the renovation choice model, that the βcc = -0.00025 and βoc = -0.00122, the discount rate is 20.79%. Assuming a technology life of 50 years for the energy retrofits to R2000 standards of home construction, the discount rate is 26.3%.

Both discount rates exceed the engineering calculations of discount rates, but are within the range of implied private discount rates for energy efficient technology adoption reported by other researchers in the revealed preference literature (Hausman, 1979, Tiedemann, 2002). However both of these estimates are significantly lower than the discount rate currently used in CIMS for home construction retrofits of 65%. This discrepancy could be attributed to the context of the choice experiment question, in which the respondent was asked to assume that they were undertaking a renovation and were not provided with a status quo option. Under this hypothetical scenario, it might be reasonable that if you intend to spend a significant amount of money in renovations, you might spend an additional amount to improve the energy efficiency of the home. If the respondents had the option not to renovate, it is plausible that the discount rate might be higher. In addition, it is important to keep in mind that the discount rate in CIMS was based on revealed preference literature that includes more than just time preferences (i.e. intangibles).

Renovation preferences

The negative sign for the standard renovation (without energy retrofits) indicates a high preference for the energy efficient renovation. This unexpected result, whereby the energy efficient alternative dominates the choice set, may be a result of respondents trying to choose the option that they believe is socially acceptable. Because the sample respondents were asked to put themselves into a hypothetical position of undertaking a renovation, the risk of situational bias is higher than if I had a sample of respondents who really were considering a renovation or had just recently performed a renovation on their home.

Considering that the market share of older homes retrofitted to meet MNECH or R2000 standards is still relatively low (NRCan, 1999), it is likely that if these results were calibrated to revealed preference data of actual renovations, I would see significant decrease in the coefficient. Revelt & Train 1998 performed such a calibration of stated preferences for an energy efficient refrigerator to revealed preference data and derived a lower coefficient value. However, even with the calibration, the preference for the energy efficient alternative remained, independent of price and operating cost savings, suggesting that consumers associate energy efficiency with higher quality, greater durability, less noise or other intangible benefits (Revelt & Train, 1998). Furthermore, many homes may have been retrofitted but not applied for certification of MNECH or R2000 standards, therefore the actual market shares may be understated and it may not be appropriate to rely on revealed preference data in this case. For simulation purposes I retain the coefficients as estimated with the discrete choice experiment, keeping in mind that home retrofits from the simulation may be higher than reality.

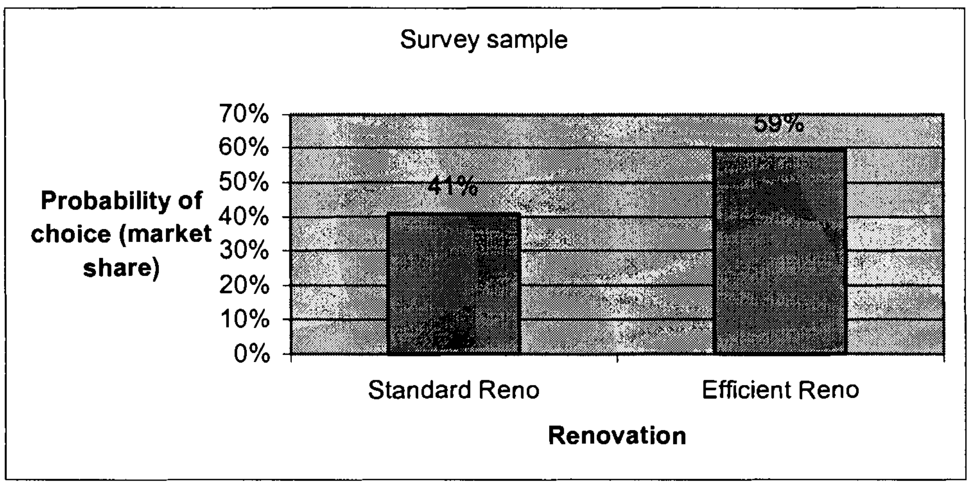
Policy effectiveness: subsidies for home renovations

The coefficient for subsidies is significant which suggests that consumers do consider the presence of a home renovation subsidy to be a positive factor in their decision-making process. While this is not surprising that consumers prefer a subsidy to no subsidy, it is interesting that most consumers do not associate subsidies with the taxes collected to fund such programs. The presence of the subsidy is explicit in the choice experiment, thereby encouraging the respondent to consider it in making a choice. In reality, the respondent may or may not be aware that a subsidy exists for a particular technology and may or may not perceive it as worthwhile to pursue. Thus if the model were again calibrated to revealed preference data, the coefficient for the subsidy may be lower because in a stated preference experiment, the consumer is aware of subsidy and doesn't have to do anything to obtain it (Revelt & Train, 1998). Further analysis of effects of a subsidy policy on the decision to invest (the action) in energy efficient renovations and heating systems is performed in Section 4.3.

Market share calculation

The discrete choice model can be used to predict the probability of market shares between alternative choices in the choice set. Using the equation from Section 2.8 (Model Specification) to estimate probabilities for each individual respondent based on the attribute values from the survey, I calculated the average probabilities for the sample of respondents for a standard renovation and for a renovation with energy efficient retrofits.

Figure 16: Market shares for renovation choices



From Figure 16, we see that on average, there is a 59% probability of selecting the energy efficient renovation compared to a 41% probability of selecting a standard renovation. The stated preferences model suggests that energy efficient renovations should have significantly more market penetration than they do currently. Depending on the type of energy retrofit, the proportion of homes in Canada who have invested in energy retrofits ranges from 1% for triple-paned windows to 13% for weatherstripping (NRCAN, 1997). While the stated preference results are encouraging to those who wish to mitigate climate change, it may suggest that the respondents tried to select the alternative that they believe is socially acceptable or that they were asked to make an unrealistic decision and thus provided an unrealistic response.

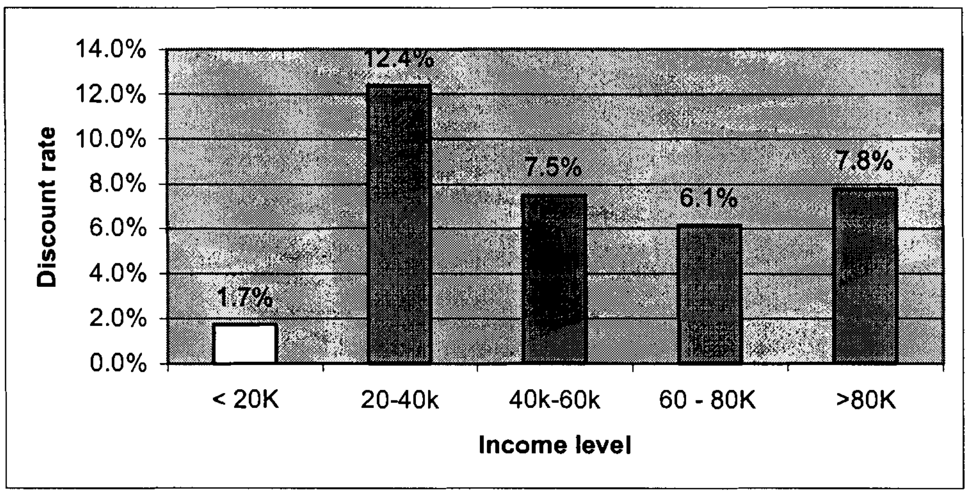
Heating system choice model: Discussion

Time preferences: Estimating a discount rate for heating choice

Using the same method of calculating the discount rate as above, I calculate a discount rate associated with investing in a heating system. The magnitude of the capital and operating cost attributes in Table 7 are similar for both the full sample model and the model that excludes oil. Both models yield a relatively low discount rate of 9%. The low discount rate indicates that respondents are concerned about operating costs. Other studies have estimated much higher discount rates for private investment in energy using equipment (Hausman, 1979, Gately 1980, Tiedemann, 2002 and Revelt & Train, 1998). Most of these studies have analyzed appliances such as air conditioners, refrigerators, and water heaters as the choice object but none of the studies I came across used heating systems. In comparison to the operating costs of appliances, annual heating costs are a larger portion of respondent's disposable income and therefore the operating costs of a heating system may be of greater concern to consumers. Furthermore a heating system has no ancillary service characteristics; it solely provides the service of heating a home. Refrigerators, ranges and other appliances have visual appeal characteristics that consumers may be sensitive to when purchasing such items. Further studies examining this phenomenon would be helpful to determine if heating systems are truly perceived differently from other energy-using appliances. Finally, Hausman (1979) showed that there might be a correlation between income level and discount rate. Although his sample sizes were very small, Hausman estimated discount rates as high as 89% for annual income under $6000, keeping in mind this study used data from the mid 1970s, to as low as 5.1% for annual income greater than $50,000. To show how the discount rate changes for different income levels, I segregated the sample by income level and estimated a model for each level.

From Figure 17, ignoring the first income category for now, the graph shows a trend of lower discount rates with higher income levels, with the exception of very high income levels, where the discount rate starts to increase again. However without another level of income beyond the last category it is difficult to determine whether this would have been an increasing trend or if it would have fluctuated minimally around the financial cost of capital (e.g. interest rate plus prime). Hausman's estimation of the discount rate for the highest income level was based on only 3 observations, whereas my data is based on 764 observations from close to 200 different respondents. However, Hausman's data is based on actual transactions while I am relying on stated preferences in a hypothetical context. But regardless of the exact trend, a lower discount rate for higher income sample appears to be justified. I have excluded the first income group from the trend analysis, as the results for this level were not statistically significant. Furthermore the lowest income level in my study are likely retired homeowners who are not necessarily representative of low income groups in the rest of society. The fact that they own their own home indicates that these respondents have accumulated a significant amount of wealth regardless of their current income stream.

Figure 17: Discount rates for heating system choice



Fuel preferences

From the results in Table 7, those respondents who do not currently use oil, higher efficiency heating systems are more preferred to lower efficiency heating systems. Again, current market shares of high efficiency natural gas furnaces do not lend support to this preference; therefore the respondents may be choosing this option partially because they believe this is the socially acceptable answer. Further model segmentation of the heating system choice experiment at a regional level is included in Table 8.

Table 8: Regional segmentation of heating choice model

Region	Atlantic	BC	Prairies	Ontario	Quebec
Attribute name					
Gross capital cost	-0.00014 *	-0.00018 *	-0.00015 *	-0.00022 *	-0.00007
Subsidy	0.0001	0.0002	0.0003	0.0004 *	0.0002
Operating cost	-0.0005	-0.0021 *	-0.0026 *	-0.0027 *	-0.0016
Responsiveness	0.163	-0.082	-0.239 *	-0.135	-0.063
Standard Eff Gas Constant	-2.06 *	0.27	-0.01	-0.49 *	-0.98
High Eff Gas Constant	-0.76 *	0.83 *	0.79 *	0.3	-0.31
Electric Constant	-0.77	-0.15	-0.48	-1.65 *	0.62
Heat pump Constant	0.77	0.57	-0.65	-0.48	-0.66
Oil Constant	referent	referent	referent	referent	referent
number of respondents	96	104	142	183	132
* a t-stat. of absolute value >1.64 = 90% confidence level					

Through regional segmentation, we see that consumers exhibit a strong preference for the energy source with the largest market share in their region even though they were told to assume that all fuel sources were available to them. For example, in the Atlantic region where natural gas is in limited supply, both the sign and the magnitude show that natural gas is less preferred to oil, whereas in British Columbia and the Prairies, natural gas is strongly preferred to oil and in Quebec, electricity is strongly preferred to oil. Unfortunately, many of the alternative specific constants on a regional basis are not significant, therefore it is difficult to draw robust conclusions from this model segmentation. However, it does appear to indicate that there is considerable resistance to change from the dominant regional energy source to an alternative energy source and that product awareness is a key choice factor. Therefore, regional differentiation of GHG emission reduction programs will be important to the success of climate change mitigation.

All regional discount rates were less than 9% with the exception of the Atlantic region, which had a discount rate of 26%. Unfortunately the operating cost attribute for the Atlantic region was not significant, therefore I do not place high confidence in this discount rate. The high discount rate combined with the very strong aversion to natural gas heating systems suggests that significant subsidies may be required to encourage people to switch from oil to natural gas once natural gas is available in the Atlantic region.

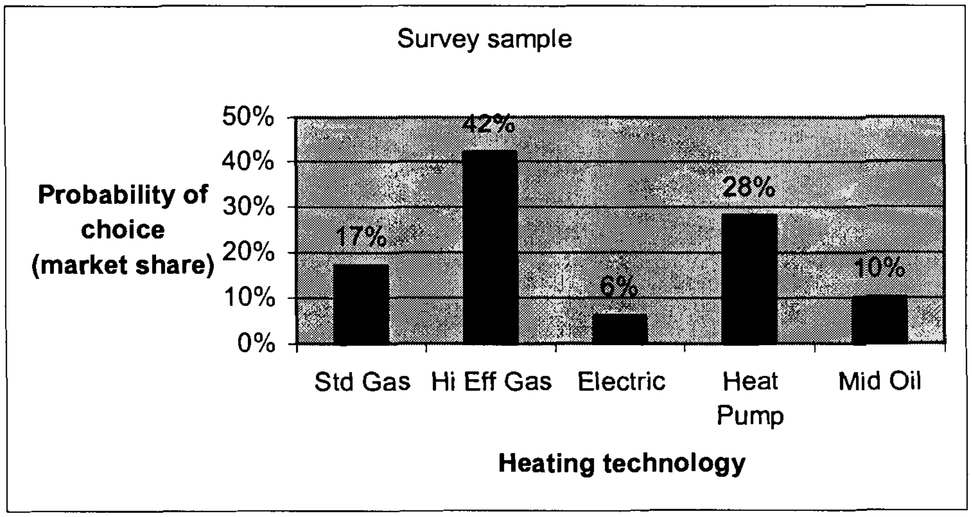
Policy effectiveness: subsidies for efficient heating systems

The significance of the subsidy attribute in the full sample model in Table 7 indicates that a well advertised subsidy could increase the adoption of energy efficient heating systems. However, looking at the regional segmentation this attribute is only significant for Ontario. The fact that this attribute is not significant in other regions does not necessarily mean that subsidies would not be effective in these regions. However sufficient variability exists among the preferences for subsidies within the small sample sizes of these regions that further analysis of the usefulness of such programs should be undertaken. Finally, the policymaker must also consider the costs involved in funding subsidy programs and if such programs are cost-effective, the policymaker must understand that the subsidy must be highly visible to the consumer and be relatively easy to apply for.

Market share calculation

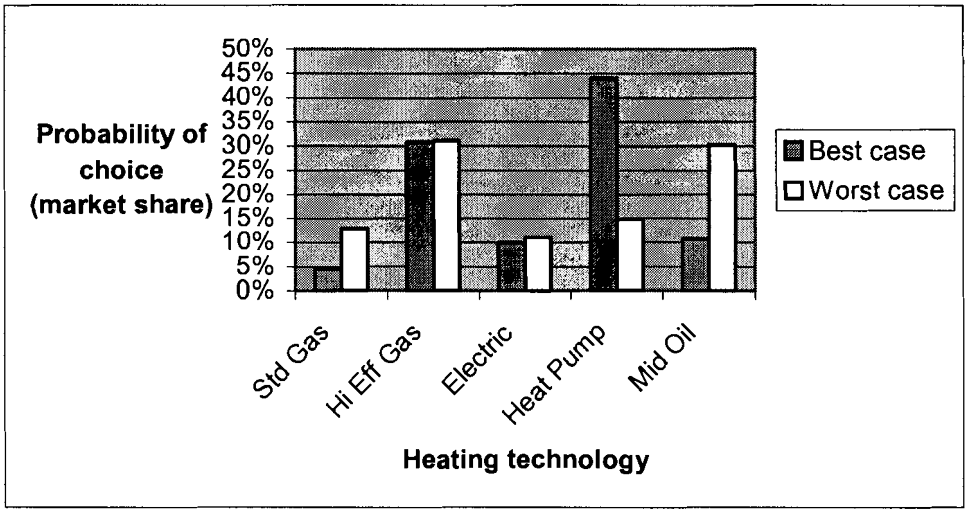
The same method of calculating the average probabilities across the sample of respondents was done using the heating system choice model parameters. From Figure 18, we see that the discrete choice model predicts higher probabilities of choice or market shares for heat pumps and high efficiency gas furnace than have currently penetrated the market. This discrepancy is explored in further detail in Section 4.1.

Figure 18: Market share for heating system choice



These sample averages represent a spread of attribute values that are wider than is currently seen in the marketplace, particularly for heat pumps and high efficiency furnaces. Therefore, the choice probabilities were also calculated using a best case and worst case scenario to illustrate the range of market shares predicted by this model. The best case is defined where the capital and operating costs of the high efficiency alternatives are at the lowest end of the range of costs used in this experiment and the worst case has the highest end of the range of costs for high efficiency alternatives. From Figure 19, we see that oil and standard gas furnaces tend to steal market share from heat pumps as the heat pumps become relatively more expensive to purchase up front.

Figure 19: Range of market share for heating system choice



Interestingly enough, the market share for high efficiency natural gas stays relatively constant indicating that from this model, a higher purchase price for high efficiency gas furnaces does not have much impact on the choice. This is consistent with the low discount rates that were estimated for this model, whereby the operating costs are more important to the consumer than the initial purchase price. Although using stated preference data means that this model may be overly optimistic in forecasting the preferences for high efficiency alternatives when compared to current market shares, such favourable results are good news for policymakers attempting to mitigate climate change. The resistance to change for space heating in the home does not refer to a resistance to the energy efficiency attribute itself but perhaps to a lack of knowledge or incentive to switch. In the next section I apply the resulting parameters from the discrete choice models to a hybrid energy economy model to simulate the effects of various incentive based policies to motivate a change in behaviour.

CHAPTER FOUR : POLICY SIMULATION

4.1 Methodology to link DCM to CIMS

To establish an empirically based forecast of behavioural characteristics in CIMS, you will recall from Section 1.5 that I need to estimate the discount rate or "r" parameter, the intangible costs or "i" parameter and the market heterogeneity or "v" parameter. In the previous section, I calculated the discount rates for both renovation choices and heating system choices. The intangible costs or benefits associated with each alternative can be calculated from the discrete choice model coefficients. The market heterogeneity parameter cannot be estimated from the discrete choice model coefficients and thus is used as a calibration parameter to equate the probability of choice (market share) predicted from the discrete choice model to the market shares predicted from CIMS.

Intangible costs in CIMS

Renovation choice

The intangible costs are calculated in the same manner as the discount rate in Section 3.4. The annual intangible cost is the ratio of the coefficient for the intangible attribute (air quality) to the coefficient for the operating costs. Assuming the energy efficient renovation has the intangible benefit of greater comfort in terms of air quality characteristics like temperature, humidity and ventilation, energy efficient renovations would have an intangible benefit of $1278 (from Table 6 = 1.559/0.00122). Including such a large intangible benefit in the life cycle cost (LCC) of the energy efficient renovation would reduce the LCC to a negative value or net benefit. This suggests that consumers perceive the benefits of high air quality to outweigh the costs of energy efficient retrofits. Given that energy efficient retrofits to the home have only achieved marginal market penetration (NRCAN, 1997) it is important to examine the assumptions and methods to ensure that this intangible benefit is appropriate to use in simulations.

Do consumers really associate an energy efficient home with higher air quality or are there other factors not considered? From the survey comments, some consumers perceive a better insulated home to be airtight and stuffy, promoting airborne bacteria and allergies even though in reality the R2000 retrofits improve indoor air quality. Thus consumers may not necessarily agree with the above assumption that energy efficient homes have higher air quality.

Furthermore, by using only two levels for this attribute being either high or low, I have assumed a linear functional form that may not be appropriate for this variable. It is likely that consumers may be satisfied with a moderate level of air quality in the home, in which case renovations without energy retrofits may provide such a level of air quality. Consumers may not be willing to pay that much more for an improvement in air quality from a moderate to a high level. Therefore, given the limitations of the current research, this intangible benefit has been excluded from the parameter estimate of "i" in CIMS.

From the alternative specific constant or renovation preference I can calculate another estimate of intangible cost that refers to other intangible factors, unobservable by the researcher, that the respondents perceive to be included in the alternatives. The annualised intangible benefit associated with an energy efficient renovation is $614 (from Table 6, 0.749/0.00122). This parameter is the annual intangible cost component of the life cycle cost in my baseline and policy runs.

Heating system choice

Similar to the renovation choice, the annual intangible cost for heating system choices is the ratio of the coefficient for the intangible attribute, the responsiveness of the heating system, to the coefficient for the operating cost attribute. Assuming that the lower efficiency heating systems, for example, standard efficiency gas and oil furnaces/boilers, take longer to reach the desired temperature than higher efficiency heating systems, then the lower efficiency heating systems have an intangible cost of $46 (from Table 7 = .079/0.0017). The high efficiency heating systems have no such intangible cost.

The annualised intangible cost for each heating system are presented below in Table 9 for the full sample, and for the regional segments. These intangible costs are calculated as the ratio of the alternative specific constants to the operating costs. Oil is used as a reference technology; thus, the alternative specific constant for oil and intangible cost for oil compared to the other technologies is zero. The choice of technology as a reference point is arbitrary. Keep in mind that these are intangible costs and therefore where the values are negative it represents an intangible benefit. These parameters are used in the baseline as the annual intangible cost.

Table 9: Intangible cost estimates for heating system choices

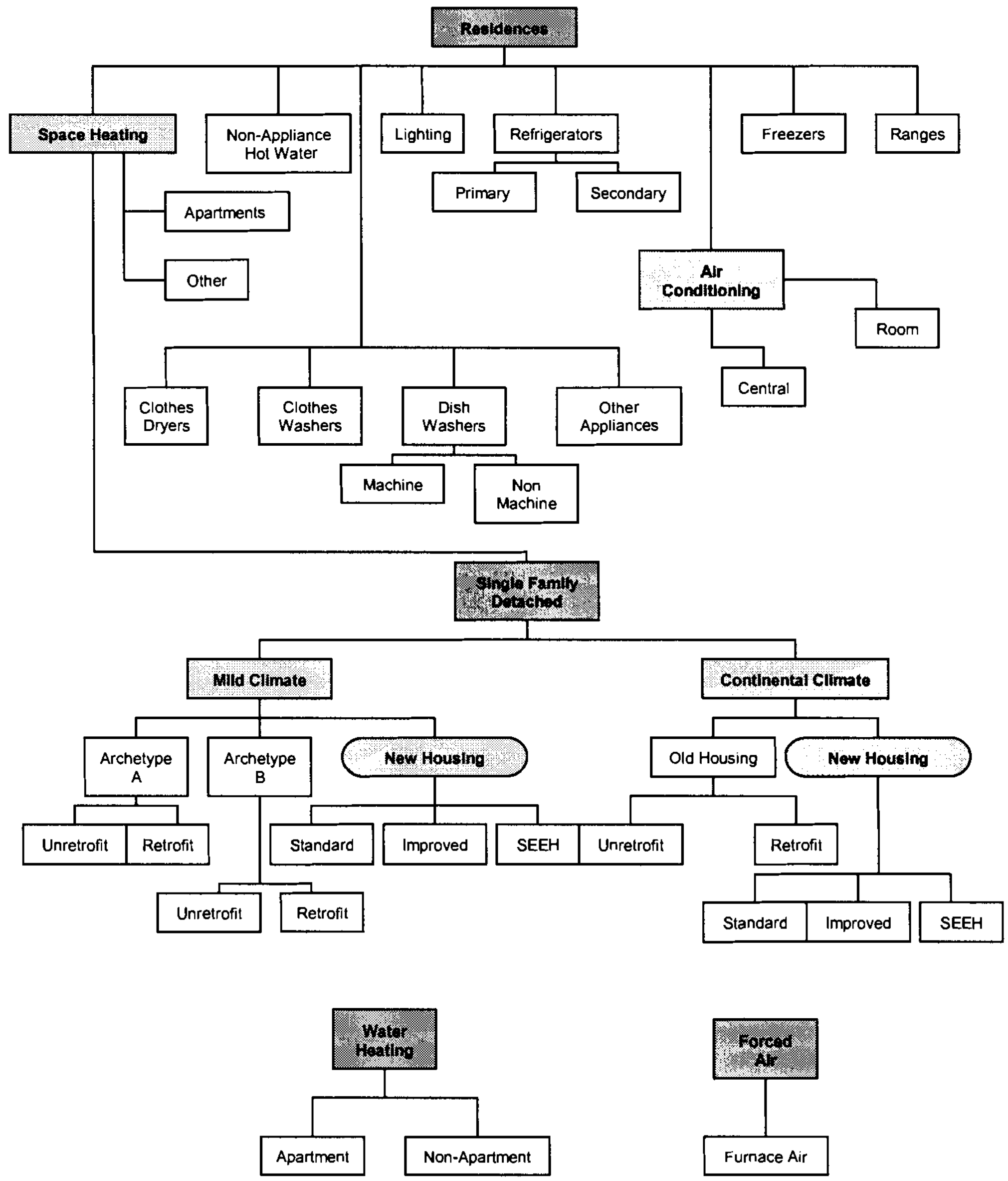
	Full sample	Ontario	Quebec	Atlantic	BC	Prairies
Standard eff natural gas	499*	179*	621*	3861*	-129	5
High eff natural gas	28	-111	197*	1415*	-403*	-297*
Electric baseboards	308*	607*	-394*	1432	70	183
Heat pumps	271*	177	417*	-1448	-277	247
Oil furnace	0	0	0	0	0	0
* = significant at the 90% confidence interval						

Market heterogeneity estimation

In CIMS, different market heterogeneity or "v" parameters can be specified at each technology competition node. In addition, a "v" parameter can be specified for the retrofit function, which in the residential sector is a retrofit from the existing household shell to a more energy efficient shell.

Figure 20 shows the energy flow model for the residential sector in CIMS. The energy service of interest is "Space Heating" and my research focuses on "Single Family Dwellings". This category is divided between regions with continental or harsher climates and those regions with temperate climates. Archetype A housing is all housing stock built prior to 1960. Archetype B housing is all housing stock built after 1960 up to the baseline year. The new housing represents stock built from the baseline year forward. My research is based on existing housing stock and thus is limited to the Archetype A and B node competitions. Within these archetypes are two technology competition nodes. The first node is called "unretrofit" and represents housing stock without household shell (e.g. the building envelope, including wall, window and door insulation) retrofits. The second node is the retrofit node, and thus represents the amount of housing shells retrofitted each year to more efficient shells. Within each of these nodes, the heating system technologies compete against each other.

Figure 20: Residential energy flow model in CIMS



As previously noted, the market heterogeneity parameter is used to calibrate CIMS to the market shares predicted by the discrete choice model. Keeping the capital and operating costs that currently exist in CIMS for attribute values for the discrete choice model, the probabilities of choice for each technology in the discrete choice model are estimated. I use the model coefficients from Table 7 to estimate a utility value for each technology. The probability of choice is estimated for each technology using Equation 6 in Section 2.1[3]. The probabilities of choice or market shares for each discrete choice experiment by household archetype are included in Table 10.

Table 10: Probability of choice per discrete choice model

		Market Share				
National: full sample		Std eff natural gas	Hi eff natural gas	Electric baseboard	Heat pump	Oil furnace
Arch A	No shell retrofits	22%	31%	8%	13%	26%
	With shell retrofits	15%	30%	16%	14%	25%
Arch B	No shell retrofits	15%	40%	9%	12%	23%
	With shell retrofits	19%	55%	2%	8%	16%
Ontario only						
Arch A	No shell retrofits	19%	59%	1%	7%	14%
	With shell retrofits	19%	47%	4%	10%	20%
Arch B	No shell retrofits	19%	55%	2%	8%	16%
	With shell retrofits	19%	51%	2%	5%	23%

These probabilities of choice predicted by the discrete choice model are then compared to the output obtained from CIMS, using the intangible cost or "i" parameter for each technology and the discount rate or "r" parameter previously calculated, for various "v" parameters until the difference between the two sets of market shares is minimized.

Table 12 in Section 4.2 provides the market shares predicted by CIMS as used to develop a baseline from which to run policy simulations. The best "v" parameter occurs where the differences between the two market share predictions are minimal or less than 2%. The best fit "v" parameters for each scenario are included in Table 11.

[3] $P_{in} = e^{V_{in}} / \quad {}_{j} \; {}_{Jn} \, e^{V_{jn}}$

Table 11: Best fit market heterogeneity parameter

	Market heterogeneity or "v" parameter	Values used in baseline
Archetype A household		
Retrofit to household shell*	1.2	0.7
Heating system without home retrofits	3.4	3.4
Heating system with home retrofits	1.75	1.75
Archetype B household		
Retrofit to household shell*	0.58	0.7
Heating system without home retrofits	2.7	2.7
Heating system with home retrofits	2.2	2.2

* - Due to programming limitations within CIMS the household retrofit parameter can only be set at one value for both archetypes therefore the value used in simulations was a value between these two (e.g. 0.7) that minimized the differences in market share.

All "v" parameters are relatively low in value compared to the "v" parameters used in past projects for CIMS because the "v" parameter was used to equate CIMS baseline to revealed preference data. A low "v" parameter means that new equipment market shares are allocated evenly across technologies even with large differences in the Life Cycle Cost. As the existing values for the "v" parameter are based on calibration to revealed preference data, in the next section I explore the difference between the market shares based on the national and regional discrete choice parameters and actual market data.

4.2 Baseline comparison

Model to market data

In order to establish an appropriate baseline from which to run simulations, I explore how parameters from the discrete choice model differ from current market data. For the sake of simplicity I have limited the policy analysis to one region. Quebec and Ontario had significant model parameters and the largest sample sizes. However, as Ontario had the larger potential emission reductions of the two regions, my analysis focuses on this region.

Table 12: CIMS market shares

		CIMS						
		Std eff gas	Hi eff gas	Total Nat'l Gas	Electric baseboard	Heat pump	Oil furnace	Other
National: full sample								
Arch A	No shell retrofits	23%	30%	53%	10%	13%	24%	n/a
	With shell retrofits	16%	31%	47%	16%	13%	24%	n/a
Arch B	No shell retrofits	16%	40%	56%	11%	11%	21%	n/a
	With shell retrofits	15%	37%	52%	12%	10%	26%	n/a
National: Actual market share 1997				45%	18%	5%	10%	22%
Ontario only								
Arch A	No shell retrofits	19%	57%	76%	3%	7%	14%	n/a
	With shell retrofits	18%	49%	67%	6%	10%	17%	n/a
Arch B	No shell retrofits	19%	56%	75%	4%	8%	14%	n/a
	With shell retrofits	16%	58%	74%	3%	5%	18%	n/a
Ontario: Actual market share 1997				63%	6%	5%	10%	18%

From Table 12, we see that both the national and the Ontario samples predict a greater preference for natural gas, oil and heat pumps compared to actual market share data. There are several explanations for this apparent discrepancy. First of all, actual market shares are based on the previous two decades of "past" decisions, whereas my research focuses on current choices or "present" decision-making. It is possible that consumers have developed a new level of awareness regarding the efficiency of heating system choices or that the focus of the survey on energy efficiency somehow biased their response. Secondly, actual market shares include an "other" heating system category representing 22% for the national population and 18% for the Ontario population. Other heating systems include wood stoves, propane, and electric and hot water furnaces. With stated preference studies all choices are equally available to the consumer, which may not be accurate in reality. Thus, the choice sets used in actual market transactions were likely different from what I used in the experiments.

According to actual market data, heat pumps comprise a very small segment of the total market share, however there is no reason not to believe that preferences might change towards heat pumps if they were readily available in the marketplace. Five years is a short time period in which to gain as much as 17% of the new market share without any incentive schemes. A more phased in approach might be more appropriate for simulation in CIMS. However, further research would need to be done to determine how fast heat pumps could reasonably penetrate the marketplace. Any attempt to set the heat pump new market share without research to support it would be completely arbitrary and would not allow us to see how heat pump shares change from the baseline with various policies.

On average, the actual market data for electric baseboard heating has a higher market share than with both national and regional based parameters. As the model parameters I estimated represent current preferences, consumers may be reacting to the uncertainty regarding electricity prices given current efforts towards deregulation of the industry, particularly in Ontario and Alberta. In addition, there may be other factors hidden in the stated preference data. Consumers may find electric heating makes the air drier than oil or natural gas and thus prefer oil or natural gas.

Regional v. National baseline

To establish a baseline, I have the option of using the discrete choice parameters based on the regional sample or the full national sample for Ontario. It is useful to look at how different the regional baseline is from the national baseline because some regions do not have statistically significant regional parameters and thus national parameters may be more appropriate.

With regional parameters for Ontario, less new market share goes to heat pumps, electric baseboards and oil furnaces than under national parameters and more share goes to natural gas, particularly high efficiency gas furnaces in Archetype A housing. In Archetype B housing, the heat pump new market share is similar for both parameter estimates; however, significantly fewer shares go to electric with regional parameters and more shares are allocated to oil. Over time the total stock of heat pumps approaches one third of the market using national parameters compared to one quarter of the market using regional parameters. The latter is more reasonable given that Ontario does not have a climate that is particularly favourable for heat pump technology and does not have cheap and clean electricity generation. Natural gas furnaces capture almost 70% of the market within 20 years under regional parameters assuming that natural gas prices decline over time.

More household shell retrofits occur under national parameters than under regional parameters because the preference for energy efficient renovations indicated by the alternative specific constant is much higher using national parameters. Therefore regional parameters are more appropriate to use in CIMS as these parameters reflect the unique circumstances of the Ontario energy and housing market. Detailed baseline data is included in Appendix C.

4.3 Policy Simulation Results

In this section, I discuss the results of several policy simulations run in CIMS: subsidies for energy retrofits in the home and high efficiency heating systems, higher efficiency regulations, and a renewable portfolio standard in the electricity sector. All policy simulations are limited to the Ontario residential model in CIMS using the regional baseline discussed above. The results are reported for direct GHG emission reductions.

Renovation subsidy

For households of both archetypes, a $1000 subsidy is quite effective at encouraging consumers to retrofit their home. Table 13 shows the percentage of households by heating system technology who retrofitted under baseline conditions compared to the percentage of households who retrofitted under the renovation subsidy policy. The decision to retrofit the household shell is independent from the heating system choice. For example, Table 13 indicates that 81% of those households heated with heat pumps will also retrofit their household shell when a $1000 home renovation subsidy is offered compared to 1.6% without the subsidy. Similarly, 97% of those households heated with electric baseboards will retrofit their household shell with the subsidy compared to 7.5% without the subsidy. Thus the straight average penetration rate of home shell retrofits with the subsidy across all heating system types and housing stock in Ontario is 86.1%[4].

---

[4] Straight average = (81+97+94+65+92+85+97+74+80+96) / 10 = 86.1%

Table 13: Household retrofit: Baseline & subsidy policy

	% Households that retrofit within 5 yrs	
Existing heating technology	**Baseline**	**$1000 subsidy**
Archetype A		
Heat pump	1.6%	81%
Electric baseboards	7.5%	97%
Std eff natural gas	8.6%	94%
High eff natural gas	3.2%	65%
Std eff oil	18.0%	92%
Archetype B		
Heat pump	4.6%	85%
Electric baseboards	5.8%	97%
Std eff natural gas	9.3%	74%
High eff natural gas	7.2%	80%
Std eff oil	18.4%	96%

Emissions of carbon dioxide, methane and nitrous oxide are lower, although not significantly lower, under the subsidy policy compared to the baseline. Table 14 shows that carbon dioxide emissions decrease by approximately 10% in the first 5 years and are 8% lower over a 10 year period.

Table 14: CO2 equivalent emissions: Household subsidy

Policy run:		000s tonnes of CO2E	
Subsidy $1000		5 years	10 years
CO2	Baseline	16,723	15,714
	Policy	15,051	14,511
	% change	10%	8%
CH4	Baseline	735	718
	Policy	625	693
	% change	15%	3%
N2O	Baseline	45	44
	Policy	38	42
	% change	16%	5%

If there were no restrictions on eligibility and no limitation of funding, this subsidy could cost over $2 billion[5] for Ontario alone! Given the infeasibility of such a proposition, policy-makers have several options: provide a limited amount of funds and issue the subsidies on a first come-first serve basis, develop eligibility criteria to restrict the number of available home subsidies, reject the subsidy policy option in favour of alternative policies that are more cost-effective or some combination of the above.

The federal government recently announced funding commitments for climate change initiatives, earmarking $131.4 million for individual incentives (NRCAN, 2003). On a proportionate basis, these limited funds would only achieve 6%[6] of the emission reductions indicated in Table 14 (107,000 tonnes CO2 equivalent) and that assumes that these funds would be committed to home renovation subsidies alone. Likely the consumers that will apply for a grant first will be the freeriders, who would have undertaken significant energy renovations even without the subsidy.

In determining what eligibility criteria to use, policy-makers must identify categories of existing households where the greatest potential for energy savings exists. One option is to restrict eligibility to older homes. But even where we restrict renovations to homes older than 1920 (i.e. 12.3% of the housing stock in Ontario), such subsidies under the above modelling exercise would cost $263 million for Ontario. The current homeowners grant announced by the federal government uses eligibility criteria, requiring a minimum improvement in energy efficiency as determined by an EnerGuide rating and home energy audit (NRCAN 2003). Unfortunately, such a program may require too much effort by the average consumer to apply for. Again, it will likely be the freeriders who take advantage of such a program. In the next few sections, I explore further policy options in the residential sector as a basis for comparison to the home renovation subsidy.

---

[5] Calculated as 3,080,000 houses in Ontario * 80.7% single family detached dwellings (NRCAN, 1997) * 86.1% that retrofit * $1000 = $2.14 billion

[6] Calculated as 131.4 / 2,140 = 6%

Subsidy: Heating system

From Table 15, you see that implementing subsidies for heat pumps and high efficiency furnaces has minimal effect on the market share for the subsidized heating system. Because the 'v' parameter value (estimated in Section 4.1) is quite low, market shares tend to be relatively evenly distributed even with large differences in Life Cycle Cost. If a higher 'v' parameter value were used, one would expect the market share of heat pumps and high efficiency furnaces to increase when subsidized. As the focus of this research is to understand how empirically derived parameters affect policy evaluation, an arbitrary change in 'v' would not be consistent with my objectives. A comprehensive uncertainty analysis on the estimation of the empirically derived parameters in this study would provide confidence intervals around the parameters, however this is outside the scope of my project.

Table 15: New stock market share: Baseline & heating system subsidies

Existing heating technology	Baseline	Heat pump subsidy $1,000	Heat pump subsidy $500	High eff gas subsidy $300
Archetype A - No home retrofits				
Heat pump	18	20	19	17
Electric baseboards	5	4	4	4
Std eff natural gas	21	21	21	21
High eff natural gas	47	46	47	49
Std eff oil	9	9	9	9
Archetype A - With home retrofits				
Heat pump	15	17	16	14
Electric baseboards	9	9	9	9
Std eff natural gas	20	20	20	19
High eff natural gas	40	39	40	43
Std eff oil	16	15	15	15
Archetype B - No home retrofits				
Heat pump	17	19	18	16
Electric baseboards	6	6	6	6
Std eff natural gas	21	20	21	20
High eff natural gas	44	43	43	46
Std eff oil	12	12	12	12
Archetype B - With home retrofits				
Heat pump	11	13	12	11
Electric baseboards	7	6	7	6
Std eff natural gas	20	20	20	19
High eff natural gas	43	42	42	45
Std eff oil	19	19	19	19

As expected with only a 2% increase in market share of heat pumps, the use of heating system subsidies does not result in significant emission reductions. The $1000 heat pump subsidy would cost approximately 50.5 million[7] with very minimal impact to the emissions scenario. Thus, policy-makers need to consider actions that are more cost effective in achieving the overall objective of reducing emissions in the residential sector.

Table 16: CO2 equivalent emissions: Heat pump subsidies

Policy run: $1000 Heat pump subsidy		000 tonnes of CO2E 5 years	10 years
CO2	Baseline	16,723	15,714
	Policy	16,662	15,608
	% change	0.4%	0.7%
CH4	Baseline	735	718
	Policy	729	709
	% change	1%	1%
N2O	Baseline	45	44
	Policy	44	43
	% change	2%	2%

Regulation: Heating system efficiency

For this policy run, I simulate an efficiency regulation that limits new market share to high efficiency natural gas furnaces only. Because low efficiency furnaces (i.e. less than 78% AFUE) are already under regulation and no longer available for new purchases, this policy targets the removal of mid efficiency models (i.e. between 78% and 90% AFUE). Thus, mid efficiency natural gas furnaces in the base stock are retired at the end of their life spans, or 15 years from now.

The distribution of new market shares is depicted in Table 17. From this distribution, we see that the other heating technologies do obtain some additional market share under the regulation, but the majority of the share from mid efficiency natural gas furnaces is reallocated to high efficiency natural gas furnaces. Policy-makers concerned about the amount of welfare cost

[7] Calculated as: 3,080,000 * 82% no heat pump in baseline * 2% increase in market share *$1000 = 50.5 million

associated with reducing the consumer choice set through regulation, may be comforted by the results from recent research on the regulation of appliances. Hatlebakk & Moxnes (2001) found that on average there is little to no reduction in consumer utility for regulatory efficiency standards on refrigerators if these still allow a considerable degree of choice in terms of models and efficiency range (among the high efficiency models). Although my project does not calculate welfare costs directly, Table 8 shows the relative preferences in Ontario for each heating system and high efficiency furnaces for my sample are actually preferred over standard efficiency furnaces. Although this suggests that consumers may not experience a welfare loss through regulation, policy-makers must bare in mind that my sample comprised a wealthier segment of the overall population. Regulations likely cause the largest welfare losses among lower income consumers.

Table 17: New market share: Baseline & regulation

	New Market share		
	Baseline	Regulation	Difference
Arch A no home retrofits	%	%	
Low Eff Natural gas	0	0	0
Mid Eff Natural gas	21	0	-21
High Eff Natural gas	47	60	13
Electric baseboard	4	6	2
Heat pump	17	22	5
Oil	9	12	3
Arch A with home retrofits			
Mid Eff Natural gas	20	0	-20
High Eff Natural gas	40	51	11
Electric baseboard	9	11	2
Heat pump	15	18	3
Oil	16	20	4
Arch B no home retrofit			
Low Eff Natural gas	0	0	0
Mid Eff Natural gas	21	0	-21
High Eff Natural gas	44	56	12
Electric baseboard	6	8	2
Heat pump	17	21	4
Oil	12	15	3
Arch B with home retrofits			
Mid Eff Natural gas	20	0	-20
High Eff Natural gas	43	53	10
Electric baseboard	7	8	1
Heat pump	11	14	3
Oil	19	24	5

In terms of emissions, from Table 18, we see that although carbon dioxide emissions are less under this policy than with the baseline, the reductions are, again, not very significant. Furthermore, carbon dioxide emission equivalents from other GHGes such as methane, and nitrous oxide actually increase under this policy due to the small market share that is now reallocated to the oil furnace technology. In CIMS, the oil technology in existing housing stock is supplemented by wood heating, which has a much higher concentration of methane and nitrous oxide associated with it than natural gas or even oil. In addition, the increased use of wood in heating contributes to other undesirable emissions from a local air quality perspective such as volatile organic compounds (VOCs). Therefore policy makers need to be careful in implementing higher efficiency regulations to ensure that they are not inadvertently encouraging the use of alternative technologies such as wood that may impact local air quality.

Table 18: CO2 equivalent emissions: Regulatory policy

Policy run: Regulation mid eff		000 tonnes of CO2E 5 years	10 years
CO2	Baseline	16,723	15,714
	Policy	16,562	15,406
	% change	1%	2%
CH4	Baseline	735	718
	Policy	787	802
	% change	-7%	-12%
N2O	Baseline	45	44
	Policy	48	49
	% change	-7%	-11%
VOCs	Baseline	17,440	17,002
	Policy	18,621	18,888
	% change	-7%	-11%

Renewable Portfolio Standard

An alternative policy to encourage clean energy use in the residential sector is to require the suppliers of electricity to obtain a certain percentage of new market share from renewable energy technologies. The switch to renewable energy technologies in the electricity sector filters down into the residential sector via increased electricity prices. Such price shocks may cause consumers to switch heating technologies or invest in home energy efficiency retrofits.

Initially the renewable portfolio standard (RPS) was set in CIMS so that renewable technologies gained 4% in total stock per 5 year period. Normally a RPS is based on new market share, however in CIMS only the total stock share can be manipulated. To gain 4% total stock by 2010, the model allocates 21.5% of new market share to renewable technologies. In the next 5 year period, renewable technologies obtain 27% of new market share. By 2015, renewables jump to 47% of the market share and by 2020, have gained 100% of new market share.

Interestingly enough, these dramatic changes in new market shares for electricity had no effect on the residential heating stock. In order to see if a higher RPS would trigger effects in the residential stock, a new policy was run to gain 20% total stock by 2010 and 20% total stock gains every 5 year period thereafter. Even at such a high RPS the 1% change in electricity price was not enough to impact the residential sector significantly. The electricity price in CIMS is based on average costing, therefore the price does not change very much with even large amounts of renewable technology penetration. While a small change in electricity prices might be significant for the amount of electricity consumed by industry or commercial sectors, it is not significant for the residential sector.

Implications for policy-makers

From the policy analysis in this section, the policy-maker may conclude that residential consumers truly are insensitive to market based policy actions such as subsidies and energy price increases, and that increased heating system standards are not particularly effective at achieving the amount of emission reductions required. Does this mean that the policy-maker should not pursue emission reduction actions in the residential sector any further?

My response to the policy-maker is that these simulations are only as useful as the model itself and the parameters that the model is based on. My project focuses on developing an empirical basis for the parameters in CIMS. Unfortunately, the one parameter that is not empirically derived, the market heterogeneity or 'v' parameter, results in a model that has minimal sensitivity to large changes in life cycle costs. As this parameter was used to calibrate the discrete choice model results to the market shares in CIMS, I have no basis for which to increase the 'v' parameter to a value large enough where we would see significant impacts from the simulation of different policy actions. Furthermore even with parameters based on revealed preferences, the contribution of the residential sector of cost-effective emission reductions is minimal at 0.6% (Jaccard et al, 2002). Validation of my results and additional research to identify other intangible factors would make the model more useful. I discuss such limitations of my research further in the next section.

Thus policy-makers should avoid policies requiring significant funding and that tend to inadvertently reward free-riders (i.e. subsidies) and focus on developing policies like information campaigns that encourage more awareness over the entire population and progressive efficiency standards that produce the tangible result of more efficient housing and heating stock. The majority of funds should be committed to the most cost-effective actions regardless of sector or region, assuming the cost estimation of these actions includes the behavioural costs associated with the emission reduction actions.

CHAPTER FIVE: CONCLUSION

5.1 Limitations of the Project

Static preferences

One of the most significant limitations to this project is the static nature of the preferences I estimated. The discrete choice survey provided us with some interesting conclusions about current fuel preferences and energy retrofit preferences but did not provide us with any idea of how those preferences might change over time. When new technologies are introduced to a marketplace, only a few early –adopters will invest in the new technology. However, one hypothesis is that after a certain percentage of the population has invested, those consumers who initially were reluctant to invest may become more willing invest. Thus some form of hurdle in terms of market penetration must be reached before the demand for the new technology takes off. I attempted to obtain some indication of how much market penetration must occur before the average consumer is willing to invest by asking respondents when they would invest in three energy-related durables: insulation, heat pumps and solar panels. However, there are problems with asking a question in this manner. Some people misunderstood the question and had to be eliminated from my analysis. It is possible that some respondents were irritated by the implication that they based their decisions on what other consumers were doing and refused to respond to the question. Finally what people say they will do and what they actually do can be quite different: a limitation to my research that I address in the next section. Ideally I would want to conduct a panel survey over time to assess the dynamics of heating system and renovation preferences. This alternative was not feasible for the current research scope but is further discussed in Section 5.2 as an option for future research projects.

Stated preferences

Although stated preference methodology has provided some valuable insights to better understand consumer behaviour and energy policy simulation, there are considerable drawbacks to stated preference studies. First of all, what people say they will do is often different from what they actually do. In my research I have not tested how the stated preferences might be reconciled to existing revealed preferences. The differences could be attributable to search costs that are not present in a stated preference survey because all of the options are placed in front of the respondent. The assumption that all options are equally available at local retailers may not be realistic.

The difference may be partially attributable to the hassle of converting systems. my survey did not factor into the choice process the respondent's existing heating system and how much time and effort would be involved in switching to a new source of energy. This unobservable but important factor probably contributed to the result that respondents tended to choose the fuel source dominant within their region.

Furthermore, my research has looked at estimating marginal preferences while existing housing stock comparisons are determined at a single point in time. There may be little difference between revealed and the stated preferences of this study once time effects are accounted for.

Other study constraints

Other limitations to my research are a product of the assumptions I made and the limited scope of this project in terms of the experimental design. In the face of imperfect knowledge, assumptions must be made about various uncertainties. For example, natural gas price forecasts are often contradictory. According to Canada's Emissions Outlook Update (CEOU, 2001) the natural gas prices are lower than expected and they forecast declining future prices. These assumptions have been used for several projects to date in CIMS. However, there is considerable concern that natural gas prices have been increasing over the past 10 years and will likely continue to do so. I have used the same declining price assumption as CEOU however I have started at a higher price as per current residential rates posted online for Ontario natural gas suppliers.

Given limitations to the experimental design, I only provided the respondent with five heating alternatives, thereby excluding wood, propane and several others. Although wood does not have a high current market share, in the face of high prices it may become a substitute for respondents in rural areas.

In this study, I have only looked at one component of the residential module in CIMS, that of existing single family dwellings. The intangible costs and behavioural factors associated with apartments, rental units and new housing have not been considered given the limited scope of this project.

Another limitation associated with the experimental design was the inability to use more than one discrete variable for each of the choice experiments (e.g. air quality for home renovations and responsiveness for heating systems). Thus, most of the intangible preference information is held within the alternative specific constants and cannot be further broken down into specific elements. From other survey questions we saw that several other factors are more or as important as price, operating costs and responsiveness to heating system choices, such as reliability, comfort level, and environmental factors.

Finally, when using discrete choice surveys of significant complexity, respondents may experience survey fatigue and not spend an appropriate amount of time assessing the tradeoffs. This typically occurs where there are too many alternatives, attributes and questions for the respondent to manage. While the survey task I used was within the lower range of complexity compared to other discrete choice survey tasks, I did have some comments regarding the length and repetition of questions, indicating that some respondents didn't perceive the questions to be different or gave up prior to finishing all the choice questions.

5.2 Suggested Future Research

As discussed previously, one aspect of this research that is not well understood is how intangible costs change over time. From a one-time only survey, this kind of dynamic preferences cannot be understood well enough to incorporate the dynamics into a hybrid energy model such as CIMS. Therefore it is recommended that future research focus on assessing these important dynamics. One method which allows the researcher to track the changes in consumer preferences is to create a panel survey that uses the same survey format over time. This before-after experimental design provides a statistically valid representation of how intangibles change over time, however there may be extraneous factors that cannot be controlled for contributing to these preference changes. The follow up surveys should be administered at lengthy intervals to ensure any policies have had time for implementation and to avoid panel recall from previous surveys.

Further validation of the parameters that I estimated through the stated preference survey is needed to reconcile to revealed preference research. One approach would be to examine in more detail the strong preference of oil as the primary energy source in the Atlantic region. This approach might involve designing a revealed preference discrete choice model for a region like B.C. where the switch from oil to natural gas occurred several years ago. The results from this discrete choice model could then be compared to a stated preference discrete choice model today. Alternatively the revealed preference model could be combined with the stated preference model so that certain parameters are estimated using one model and the remaining parameters are estimated using the other model.

The results from my research could be improved by using a more robust experimental design. More than two levels of attributes could be used to assess any nonlinearties in preferences. Different attributes could be used to examine how other discrete variables might be contributing to the large alternative specific constants. One way to better assess the impact of information campaigns would be to segment the sample so that half the sample received no additional information and the other half received information to determine if there were any significant differences in heating system choices or home renovation choices. Different segments of the population, such as renters and new home buyers could be targeted to determine if choices are made using different discount rates and intangible factors. Improvements such as these to the experimental design would reduce the uncertainties created by stated preference discrete choice approaches and increase the validity of my results.

5.3 Overall Conclusions

In order to determine what policies are most cost effective at achieving the objective of increasing energy efficient technology adoption and fuel switching to reduce GHG emissions, I needed to better understand consumer preferences, to quantify preferences into estimates of intangible costs and to incorporate the resulting parameters into a hybrid simulation model. The survey, including two discrete choice experiments, provided me with the preference data. A discrete choice model of this data provided the time preference parameters and intangible cost estimates. Finally, by using these empirically based parameters in the CIMS hybrid energy economy model, I was able to simulate various residential energy policies and assess their effectiveness. I next highlight some key conclusions from each of these three project components.

Preference data

In general, respondents preferred energy efficient renovations over renovations without any energy retrofits. Respondents used a higher discount rate for the renovation choice than for the heating system choice but at 21%, their time preference was not as high as other research might indicate. Given that I have separated the effects of intangible costs from the time preference parameter, I believe that this is a reasonable empirically based estimate of the discount rate for home renovations.

Surprisingly, respondents had strong preferences for more efficient heating systems like high efficiency gas furnaces and heat pumps. This could be an indication of a changing attitude among homeowners whereby higher efficiency is perceived to yield significant net benefits. Although the ease of choice in a stated preference survey may result in an overstatement of these choices compared to what has actually occurred in the market. The time preference of 9% indicates that respondents did not perceive as much risk in a heating system investment as compared to an investment in home retrofits. The fact that this discount rate is low compared to other studies can be explained by the significance of heating costs in the household and income effects.

Intangible cost estimation

Respondents perceive a significant intangible benefit to significant air quality improvements. However, I cannot be certain that consumers really do associate an energy efficient home with high air quality. Future research should be done to assess these perceptions.

The intangibles associated with heating systems are only partially explained by the responsiveness of the system. Considering the size and statistical significance of the alternative specific constants for each heating technology, many other intangible factors contribute to consumers fuel preferences.

Policy implications

From my policy analysis, I concluded that policy-makers should avoid subsidy policies, which are very cost intensive, particularly given the minimal impact on emission reductions, in favour of progressive regulatory and information campaigns. Indeed, if consumers were aware that the commitment of subsidies might result in the reallocation of funds from other social services or by the raising of taxes, they would be less in favour of subsidy programs. By allowing sufficient lead times for manufacturers to cost efficiently change over the stock that is on the market, the high capital costs associated with higher efficiency stock can be mitigated. Based on the survey results, most consumers are only strongly opposed to increased energy prices, thus indicating that other policy measures have less welfare losses associated with them. While the effects of information campaigns were not specifically addressed in this research, such campaigns do not cost much to administer (Nanduri et al), and they can be helpful in educating the public, perhaps to eventually support more effective regulatory policies.

Model implications

Because parameters based on the empirical support of stated preferences better reflect the current preferences of today's consumer, I am fully supportive of retaining the intangible cost parameters and the discount rates as used in my policy simulations for other projects using CIMS. Policy programs are aimed at future actions, thus, the more current the preference research, the more relevant it is to policymakers. Given the relative novelty of combining stated preference research with hybrid energy economy modelling, support for my research could be enhanced by replicating or further developing the experimental design to be more comprehensive in the identification of intangible factors that drive behavioural costs.

This project has highlighted the advantages of using a hybrid model by incorporating the behavioural intangible costs into the technology competition to simulate actions resulting from policy programs. It provides a more accurate picture of where consumer preferences are heading and thus is more useful than the top-down models that are based on historical trends and the bottom-up models that fail to account for consumer preferences at all.

APPENDIX A: TELEPHONE RECRUITING SURVEY

Hello, this is ____ from MarkTrend. The Energy & Materials Research Group at Simon Fraser University in British Columbia is currently conducting a study of households across Canada about home energy use. The purpose is to understand how homeowners make choices between home renovation and heating options.

The study has two parts – a few questions today on the phone, followed by a simple questionnaire delivered to you by mail that will take no more than 20 minutes to complete. All responses will be treated confidentially. For every completed and returned survey, we will donate $1 to UNICEF.
IF RESPONDENT WANTS TO VERIFY SURVEY, THE NUMBER IS 604-268-6621

1. Your household is one of those chosen to represent (INSERT PROVINCE). Would you be willing to participate in both parts of the survey?

1. Yes
2. No — Before you go, could you please tell us why you are unwilling to participate in this study? <<*Conclude interview*>>
    1. Time
    2. Privacy
    3. Don't do surveys
    96. Other (specify)
    97. No response/refused

PART A: Recruitment

2. Firstly, is your home a single detached house?

1. Yes - Single detached house
2. No – (condo/townhouse/duplex/all others) -- Unfortunately, we are currently assessing energy related behaviour that is more relevant for those in houses. Thank you for your time, this concludes our interview.

3. Do you own the house you are living in?

1. Yes
2. No — Unfortunately, this survey targets homeowners, is there anyone else in the household available to speak with us who would qualify? <<*if yes, introduction, otherwise conclude interview*>>

4. Are you 18 years of age or older?

1. Yes
2. No May we please speak to someone in the household over the age of 18? *If yes, repeat introduction, otherwise, conclude interview.*

PART B: Energy use characteristics

1. Are the following fuels available in your area?

a) Natural gas
1. Yes
2. No
?. Don't know

b) Oil
1. Yes
2. No
?. Don't know

2. Which of the following is the primary system for heating your home?

1. Electric baseboard
2. Natural gas furnace
3. Oil furnace
4. Wood burning fireplace or stove
5. Ground source heat pump
96. Other (specify)
?. Don't know

3. How often are you billed for your heating?

1. Monthly
2. Every 2 months
3. Every 3 months
96. Other (specify)
?. Don't know

4. Approximately, how much is your average heating bill?

$_____
? Don't know *(prompt for an approximate amount)*

Conclusion

That's it for the telephone part of the study. The mail questionnaire will be arriving in the mail within one week.

Who should we address the mail questionnaire to? ______________________________

To ensure our records are accurate, would you please confirm your mailing address for us.

INSERT ADDRESS FROM LISTING RECORDS. MODIFY ADDRESS AS NECESSARY.

Would you prefer your questionnaire to be in English or in French?

1. English
2. French

On behalf of the Energy and Materials Research Group, we thank you for being part of this important study.

APPENDIX B: CANADIAN HOME ENERGY STUDY SURVEY

Simon Fraser University

CANADIAN HOME ENERGY STUDY

Energy and Materials Research Group

Thank you for agreeing to participate in our survey. Remember that with each received survey, we will donate $1 to Unicef.

You will be asked a number of questions regarding your home energy use and preferences. Your opinions and ideas are important, so please answer each question. The following sample illustrates the format that will be used.

Sample Question

Question (plain text)

Instructions (italicized)

1. To what degree would you say you are aware of the level of energy efficiency of the following home energy features? *Please check the best response for each feature.*

	Awareness of energy efficiency				
	Unaware		Somewhat aware		Aware
Home construction (e.g. insulation, windows)	☐	☑	☐	☐	☐
Heating system (e.g. furnace, wood stove)	☐	☐	☐	☑	☐
Appliances (e.g. fridge, washer/dryer)	☐	☐	☑	☐	☐

Home energy features

Your Answers

The survey should take approximately 20 minutes to complete.

Part 1 – General home characteristics and level of energy efficiency

1. When was your home originally built? *Please indicate the approximate date if you are uncertain.*

❑	Before 1941	❑	1971 to 1980
❑	1941 to 1950	❑	1981 to 1990
❑	1951 to 1960	❑	1991 to 2000
❑	1961 to 1970	❑	After 2000

2. Approximately, what is the total heated living area of your home (excluding garage and storage area)? *Please record the size and indicate the corresponding measurement unit.*

	Square feet	Square meters	Don't know
____________	❑	❑	❑

3. How many people normally reside in your home? __________ people

4. To what degree would you say you are aware of the level of energy efficiency of the following features of your home? *Please check the best response for each feature.*

	Awareness of energy efficiency				
	Unaware		Somewhat aware		Aware
Home construction (e.g. insulation, windows)	❑	❑	❑	❑	❑
Heating system (e.g. furnace, wood stove)	❑	❑	❑	❑	❑
Appliances (e.g. fridge, washer/dryer)	❑	❑	❑	❑	❑

5. How long have you owned your home?

- ❑ Less than 2 years
- ❑ 2 to 5 years
- ❑ 6 to 10 years
- ❑ 11 to 15 years
- ❑ 16 to 20 years
- ❑ More than 20 years

6. Which of the following energy saving features does your home have and who invested in the feature? *Please check one response for each energy saving feature.*

	Features present in your home			
Energy saving features	Yes, you invested in this feature	Yes, previous owners or builders invested in this feature	No, our home does not have such features	Don't know if our home has such features
At least 1/3 of windows are double (or triple) paned	❑	❑	❑	❑
Weather-stripping on doors	❑	❑	❑	❑
High efficiency furnace/boiler	❑	❑	❑	❑
Programmable thermostat	❑	❑	❑	❑
Hot water tank blanket	❑	❑	❑	❑
At least ¼ of light bulbs are fluorescent	❑	❑	❑	❑
Other, please specify: ________	❑	❑	❑	❑

7. How would you rate the air quality (e.g. ventilation, humidity) of your home? *Please check the best response.*

❑ Excellent ❑ Good ❑ Fair ❑ Poor ❑ Don't know

8. Do you have any comments on the answers you provided in this section of the survey?

____

____

Part 2 – Renovation choices

For this section, assume that you are considering a renovation to your home, involving upgrades to the structural characteristics of the home. Each question asks you to choose between carrying through with your intended renovation as is, or incorporating retrofits to improve the efficiency of your home. Retrofits would include better insulation in the walls, ceiling, and floors, weather stripping around the doors, and replacing single-paned windows with double- or triple-paned windows. For each question, you will need to make tradeoffs according to which attributes are the most important to you.. Please read over the attributes, and indicate which option you would prefer.

9. If these were the only renovation options available to you, which one would you choose?

Attributes	*General Renovation*	*Improved Efficiency Renovation*
Cost	$6000	$12000
Subsidy[8]	$0	$0
Total Cost	$6,000	$12,000
Heating costs/year	$1600	$800
Comfort level[9]	High air quality	High air quality
	❑	❑

10. If these were the only renovation options available to you, which one would you choose?

Attributes	*General Renovation*	*Improved Efficiency Renovation*
Cost	$6,000	$12,000
Subsidy[1]	$0	$500
Total Cost	$6,000	$11,500
Heating costs/year	$1200	$1000
Comfort level[2]	High air quality	Low air quality
	❑	❑

[8] Assume that subsidies for improving the level of home insulation are available from the government or your energy supplier.

[9] Comfort level is defined as the air quality within the home, including ventilation, humidity and temperature.

11. If these were the only renovation options available to you, which one would you choose?

Attributes	*General Renovation*	*Improved Efficiency Renovation*
Cost	$6,000	$12,000
Subsidy[1]	$0	$500
Total Cost	$6,000	$11,500
Heating costs/year	$1200	$1000
Comfort level[2]	High air quality	Low air quality
	❑	❑

12. If these were the only renovation options available to you, which one would you choose?

Attributes	*General Renovation*	*Improved Efficiency Renovation*
Cost	$6,000	$12,000
Subsidy[1]	$0	$1000
Total Cost	$6,000	$11,000
Heating costs/year	$1600	$800
Comfort level[2]	Low air quality	High air quality
	❑	❑

13. Do you have any comments on the choices you made in this section of the survey?

____

____

____

____

Part 3 – Your Heating system choices

In this section, assume that you need to replace your existing heating system. Each question asks you to choose between different heating systems. For each question, your will need to make tradeoffs according to which attributes are the most important to you. Please read over the attributes, and indicate which heating system you would prefer. Please assume that all fuel types are available in your region.

14. If these were the only four heating systems available, which one would you choose?

	Standard Efficiency Gas Furnace/Boiler	***High Efficiency Gas Furnace/Boiler***	***Electric baseboard heating***	***Heat pump – ground source***[10]
Purchase price	$2,200	$3,200	$1,400	$13,000
Subsidy	$0	$300	$0	$1000
Total cost:	$2,200	$2,900	$1,400	$12,000
Operating costs/ year[11]	$1400	$800	$1900	$300
Responsiveness [12]	Within 1 hour	Within 1 hour	Within 1 hour	Within 1 hour
	☐	☐	☐	☐

15. If these were the only four heating systems available, which one would you choose?

	Standard Efficiency Oil Furnace/Boiler	***High Efficiency Oil Furnace/Boiler***	***Electric baseboard heating***	***Heat pump – ground source***[3]
Purchase price	$2,700	$3,200	$1,400	$13,000
Subsidy	$0	$0	$0	$0
Total cost:	$2,700	$3,200	$1,400	$13,000
Operating costs/ year[4]	$1400	$1200	$1300	$200
Responsiveness	Within ½ hour	Within 1 hour	Within 1 hour	Within 1 hour
	☐	☐	☐	☐

---

[10] A ground source heat pump is an electrical device that extracts heat from the ground or groundwater and transfers the heat to the air within the home. They are also known as geothermal heating systems or earth energy systems.

[11] Operating costs are derived from the energy efficiency of the heating system and the price of energy per unit of measurement.

[12] Responsiveness indicates how quickly the home reaches the desired temperature.

16. If these were the only four heating systems available, which one would you choose?

	Standard Efficiency Oil Furnace/Boiler	***High Efficiency Oil Furnace/Boiler***	***Electric baseboard heating***	***Heat pump – ground source[3]***
Purchase price	$2,200	$4,000	$1,400	$13,000
Subsidy	$0	$0	$0	$1000
Total cost:	$2,200	$4,000	$1,400	$12,000
Operating costs/ year[4]	$1000	$1200	$1300	$300
Responsiveness[5]	Within 1 hour	Within ½ hour	Within ½ hour	Within 1 hour
	❑	❑	❑	❑

17. If these were the only four heating systems available, which one would you choose?

	Standard Efficiency Gas Furnace/Boiler	***High Efficiency Gas Furnace/Boiler***	***Electric baseboard heating***	***Heat pump – ground source[3]***
Purchase price	$2,700	$4,000	$1,400	$13,000
Subsidy	$0	$300	$0	$0
Total cost:	$2,700	$3,700	$1,400	$13,000
Operating costs/ year[4]	$1000	$800	$1900	$200
Responsiveness[5]	Within ½ hour	Within ½ hour	Within ½ hour	Within 1 hour
	❑	❑	❑	❑

18. Do you have any comments on the choices you made in this section of the survey?

____

____

____

Part 4 – Motivations for Investment in Energy Efficiency

19. a) Have you ever purchased a new heating system for your home?

- ❑ Yes
- ❑ No

b) If you answered yes, please indicate the heating system that you chose:

- ❑ Natural gas furnace/boiler
- ❑ Oil furnace/boiler
- ❑ Electric baseboard heating
- ❑ Heat pump
- ❑ Other ________________*(please specify)*
- ❑ Don't know

20. How important to you are each of the following factors in making a decision to purchase a new heating system? *Please check the best response for each factor.*

	Importance of Factor in Purchasing Decision			
	Not important at all	Somewhat important	Important	Very Important
Equipment purchase price	❑	❑	❑	❑
Operating costs	❑	❑	❑	❑
Reliability	❑	❑	❑	❑
Responsiveness (time it takes to reach desired temperature)	❑	❑	❑	❑
Comfort (e.g. internal air quality, temperature, noise)	❑	❑	❑	❑
Concern for the environment	❑	❑	❑	❑
Labels indicating energy efficiency	❑	❑	❑	❑
Energy prices	❑	❑	❑	❑
Other: ______________	❑	❑	❑	❑

21. For each condition, please indicate whether or not you would invest in each energy efficient device. *Place a check if you would invest, otherwise leave the box blank.*

Condition		**Energy Efficient Device**		
	Would you invest in the following energy efficient devices, if...	Improved insulation	Heat pump	Solar panels
a)	**Nobody has invested in this before.**	❑	❑	❑
b)	Some people have invested & successfully cut energy costs.	❑	❑	❑
c)	Many people have invested & successfully cut energy costs.	❑	❑	❑
d)	Everybody has invested & successfully cut energy costs.	❑	❑	❑

22. What is your level of support for the following home energy policies? *Please check the best answer for each group of policies, with 1 being strongly opposed, and 5 being strongly supportive.*

	Your Degree of Support					
	Strongly opposed 1	2	3	4	Strongly supportive 5	Don't Know
Increasing energy efficiency standards for new homes.	❑	❑	❑	❑	❑	❑
Increasing energy efficiency standards for new heating systems.	❑	❑	❑	❑	❑	❑
Providing subsidies to improve home insulation levels.	❑	❑	❑	❑	❑	❑
Providing subsidies for the purchase of high efficiency heating systems.	❑	❑	❑	❑	❑	❑
Raising energy prices to encourage energy efficiency.	❑	❑	❑	❑	❑	❑
Labeling programs that provide more information regarding the efficiency of homes and heating systems.	❑	❑	❑	❑	❑	❑

23. Do you have any comments on the answers you provided in this section of the survey?

____

____

____

____

Part 6 - Additional Information About Yourself

24. In 2001, which category best describes your total family income, before tax?

- ❑ $20,000 or less
- ❑ $20,001 to $40,000
- ❑ $40,001 to $60,000
- ❑ $60,001 to $80,000
- ❑ $80,001 or over

25. What is the highest level of education you have completed?

- ❑ Less than Grade 9
- ❑ Grade 9
- ❑ Grade 12
- ❑ College or other post-secondary diploma
- ❑ University

26. What is your age?

- ❑ 25 years or less
- ❑ 26 to 45 years
- ❑ 46 to 65 years
- ❑ 66 years or older

27. What is your gender?

- ❑ Female
- ❑ Male

28. What is your current occupation? ______________________________

Thank you again for taking the time to help us.

If you have any questions about this survey, or the research in general, please contact the primary researcher, Margo Sadler.

Phone: 604-268-6621
Email: mcsadler@sfu.ca

If you would like to speak to a representative of the School of Resource and Environmental Management at Simon Fraser University, please contact the director, Frank Gobas.

Phone: 604-291-4659

Once you have completed this survey, please return it in the enclosed postage paid envelope to the following address:

Canadian Home Energy Study
EMRG/CIEEDAC
Room 2123 East Academic Annex
Simon Fraser University
8888 University Drive
Burnaby, BC V5A 1S6

If you would like to see the results of this study, updates will be regularly posted at the following website:

http://www.emrg.sfu.ca/homeenergy

APPENDIX C: BASELINE DATA FOR SIMULATIONS

	Ontario - Archetype A					
	Std Eff Gas	Hi Eff Gas	Electric	Heat pump	Oil furnace	Home retrofit
Capital cost						10081
nonretrofit	2557	3100	2302	5440	4092	
with retrofit	2557	3100	2302	5440	4092	
Operating cost						note 1
nonretrofit	820	702	1575	1036	983	
with retrofit	228	198	439	288	274	
"v" parameter						note 2
nonretrofit	3.4	3.4	3.4	3.4	3.4	
with retrofit	1.75	1.75	1.75	1.75	1.75	
"i" parameter						note 3
nonretrofit	367	31	749	319	188	
with retrofit	225	-111	607	177	46	
"r" parameter						0.1256
nonretrofit	0.08	0.08	0.08	0.08	0.08	
with retrofit	0.08	0.08	0.08	0.08	0.08	

	Ontario - Archetype B					
	Std Eff Gas	Hi Eff Gas	Electric	Heat pump	Oil furnace	Home retrofit
Capital cost						5828
nonretrofit	2557	3100	2302	5465	4092	
with retrofit	2557	3100	2302	5465	4092	
Operating cost						note 1
nonretrofit	586	497	1126	741	703	
with retrofit	438	372	842	726	424	
"v" parameter						note 2
nonretrofit	2.7	2.7	2.7	2.7	2.7	
with retrofit	2.2	2.2	2.2	2.2	2.2	
"i" parameter						note 3
nonretrofit	367	31	749	319	188	
with retrofit	225	-111	607	177	46	
"r" parameter						0.1256
nonretrofit	0.08	0.08	0.08	0.08	0.08	
with retrofit	0.08	0.08	0.08	0.08	0.08	

note 1: Operating cost savings can be derived by subtracting the operating cost for each technology for the "nonretrofit" nodes from the "with retrofit" nodes.

Note 2: The retrofit "v" parameter used was 0.7. Due to model limitations of CIMS, we were unable to differentiate between Archetype A and B housing for this parameter.

Note 3: An intangible benefit of $142 was added to "with retrofit" "i" parameter.

APPENDIX D: ETHICS APPROVAL

SIMON FRASER UNIVERSITY

OFFICE OF RESEARCH ETHICS

BURNABY, BRITISH COLUMBIA
CANADA V5A 1S6
Telephone: 604-291-3447
FAX: 604-268-6785

October 31, 2002

Ms. Margo Sadler
Graduate Student
School of Resource &
Environmental Management
Simon Fraser University

Dear Ms. Sadler:

Re: Incorporating Choice-Based Parameters in Residential Energy Modeling

I am pleased to inform you that the above referenced Request for Ethical Approval of Research has been approved on behalf of the Research Ethics Board. The approval for this project is for the term of the period of the grant, as defined by the funding agency. If this project does not receive grant support, the term of the approval is twenty-four months from the above date.

Any changes in the procedures affecting interaction with human subjects should be reported to the Research Ethics Board. Significant changes will require the submission of a revised Request for Ethical Approval of Research. This approval is in effect only while you are a registered SFU student.

Your application has been categorized as 'minimal risk" and approved by the Director, Office of Research Ethics, on behalf of the Research Ethics Board in accordance with University policy R20.0, http://www.sfu.ca/policies/research/r20-01.htm. The Board reviews and may amend decisions made independently by the Director, Chair or Deputy Chair at its regular monthly meetings

"Minimal risk" occurs when potential subjects can reasonably be expected to regard the probability and magnitude of possible harms incurred by participating in the research to be no greater than those encountered by the subject in those aspects of his or her everyday life that relate to the research.

Best wishes for success in this research.

Sincerely,

Dr. Hal Weinberg, Director
Office of Research Ethics

c: Mark Jaccard, Supervisor
/jmv

REFERENCE LIST

Ball, R., R. Cullen, et al. (1999). "The diffusion of energy efficiency innovations among residential energy consumers." New Zealand Economic Papers **33**(1): 115-135.

Bataille, C. (1998). Capital for energy and inter-fuel elasticities of substitution from a technology simulation model: estimating the cost of greenhouse gas reduction. School of Resource and Environmental Management. Burnaby, Simon Fraser University.

Ben-Akiva, M. and S. Lerman (1985). Discrete choice analysis: theory and application to travel demand. Cambridge, MIT Press.

Berry, T. and M. Jaccard (2001). "The renewable portfolio standard: design considerations and an implementation survey." Energy Policy **29**: 263-277.

de Vaus, D. (1995). Surveys in Social Research. Australia, Allen & Unwin.

Deal, K. and D. Mountain (2001). Discrete choice evaluation of OEE market transformation programs: Initial rough draft, Natural Resources Canada.

Edwards, C., M. Adelaar, et al. (1999). Residential Sector Climate Change Foundation Paper, National Climate Change Secretariat.

Energy and Materials Research Group (EMRG) (1998). Cost curve estimations for reducing CO2 Emissions in Canada: An analysis by province and sector. Burnaby, Natural Resources Canada.

Gately, D. (1980). "Individual discount rates and the purchase and utilization of energy-using durables: comment." Bell Journal of Economics **11**(1): 372 - 374.

Gujarati, D. N. (2003). Basic Econometrics, McGraw Hill.

Hartman, R. S. and M. J. Doane (1986). "Household discount rates revisited." The Energy Journal **7**(1): 139-148.

Hatlebakk, M. and E. Moxnes (2001). "Estimating customer costs or benefits of energy efficiency standards for refrigerators." Unpublished manuscript.

Hausman, J. A. (1979). "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables." The Bell Journal of Economics **10**(1): 33-54.

Hutton, R. B. and W. L. Wilkie (1980). "Life Cycle Cost: A New Form of Consumer Information." Journal of Consumer Research **6**(March): 349-359.

Jaccard, M. (2002). Costing GHG Abatement: Canada's Technological and Behavioural Potential. Burnaby, Energy and Materials Research Group.

Jaccard, M., A. Bailie, et al. (1996). "CO2 emission reductions costs in the residential sector: Behavioral parameters in a bottom-up simulation model." The Energy Journal **17**(4): 107-134.

Jaccard, M., A. Bailie, et al. (2001). Assessing the Cost of GHG Abatement Policies: A Methodology and a Case Study, ACEEE Summer Study on Energy Efficiency: 609-620.

Jaccard, M. and C. Bataille (2003). "If Sustainability is Expensive, What Roles for Business & Government? A Case Study of GHG Reduction Policy in Canada." Unpublished manuscript.

Jaccard, M., J. Nyboer, et al. (2002). The Cost of Climate Policy. Burnaby, UBC Press.

Jaffe, A. and R. Stavins (1994). "Energy efficiency investments and public policy." The Energy Journal **15**: 43-65.

Jaffe, A. and R. Stavins (1994). "The energy paradox and the diffusion of conservation technology." Resource and Energy Economics **16**: 91-122.

Louviere, J. (2001). Choice experiments: An overview of concepts and issues. The Choice Modeling Approach to Environmental Valuation. J. Bennett and R. Blamey. Cheltenham, UK.

Louviere, J., D. Hensher, et al. (2000). Stated Choice Methods: Analysis and Applications. Cambridge, Cambridge University Press.

Marbek Resource Consultants (1999). Building Table Options Report: Residential Sector.

Metcalf, G. and K. Hasset (1999). "Measuring the energy savings from home improvement investments: Evidence from monthly billing data." The Review of Economics & Statistics **81**(3): 516-528.

MK Jaccard & Associates (2002). Construction and Analysis of Sectoral, Regional and National Cost Curves for GHG Abatement in Canada, National Climate Change Implementation Process: 137-150.

Montgomery, D. C. (1991). Design and Analysis of Experiments. New York, John Wiley & Sons, Inc.

Nanduri, M., K. Tiedemann, et al. (2002). Using Choice Experiments in Energy Program Evaluations: The Case of EnerGuide. Ottawa, Natural Resources Canada.

National Climate Change Process (1999 a). Residential Sector Climate Change Foundation Paper. Ottawa, National Climate Change Process. http://www.nccp.ca/NCCP/national_process/issues/buildings_e.html#options. Accessed: September 22, 2003.

National End Use Database (2002). Residential Space Heating Energy Use and System Stock Share, Office of Energy Efficiency. http://oee.nrcan.gc.ca/neud/dpa/tables/3a.xls. Accessed: September 22, 2003.

Natural Resources Canada (NRCan) (1997). Survey of Household Energy Use. Ottawa.

Natural Resources Canada (NRCan) (1999). Improving Energy Performance in Canada: Report to Parliament under the Energy Efficiency Act, http://www.oee.nrcan.gc.ca/infosource/pdfs/repparle.pdf. Accessed: July 5, 2002.

Natural Resources Canada (NRCan) (2000). Energy in Canada 2000. Ottawa, Office of Energy Efficiency: http://www2.nrcan.gc.ca/es/ener2000/online/html/chap4c_e.cfm. Accessed: September 22, 2003.

Natural Resources Canada (NRCan) (2001). State of Energy Efficiency in Canada 2001, http://energy-publications.nrcan.gc.ca/index_e.cfm. Accessed: July 5, 2002.

NRCAN (2003). Government of Canada Announced $1 Billion Toward Implementation of Climate Change Plan, www.climatechange.gc.ca/english/publications/announcement/news_release.html. Accessed: September 22, 2003.

Office of Energy Efficiency (2002). Guide to Canada's Energy Efficiency Regulations, http://www.oee.nrcan.gc.ca/regulations/guide.cfm?text=N. Accessed: November 23, 2002.

Pal, L. A. (2001). Beyond Policy Analysis: Public Issue Management in Turbulent Times. Scarborough, Nelson Thomson Learning.

Poortinga, W., L. Steg, et al. (2003). "Household preferences for energy-saving measures: A conjoint analysis." Journal of Economic Psychology **24**: 49-64.

Revelt, D. and K. Train (1998). "Mixed logit with repeated choices: Household's choices of appliance efficiency level." Review of Economics and Statistics **LXXX**(4): 647-657.

Rogers, E. M. (1995). Diffusion of Innovations. New York, The Free Press.

Rowlands, H., P. Parker, et al. (2000). "Strategies for a softer, more sustainable, residential energy path." Environments **28**(3): 121-145.

Ruderman, H., M. Levine, et al. (1987). "The behaviour of the market for energy efficiency in residential appliances including heating and cooling equipment." The Energy Journal **8**(1): 101-123.

Salant, P. and D. Dillman (1994). How to Conduct Your own Survey. Toronto, John Wiley & Sons, Inc.

Scott, D., P. Parker, et al. (2000). "Determinants of Energy Efficiency in the Home: A Case Study of Waterloo Region." Environments **28**(3): 73-95.

Scott, D., H. Rowlands, et al. (2000). "Integrating technical and social energy studies: Prospects for change in Canadian residential sector." Environments **28**(3): 2-10.

Sutherland, R. (2000). "No Cost efforts to reduce carbon emissions in the U.S.: An economic perspective." The Energy Journal **21**(3): 89-113.

Tiedemann, K. (2002). Discrete Choice Modelling of Appliance Fuel Choice. Vancouver.

Train, K. (1986). Qualitative Choice Analysis: Theory, Econometrics and an Application to Automobile Demand. London, The MIT Press.

Train, K. (2002). Discrete Choice Methods with Simulation. Berkeley, Cambridge University Press.