University of Alberta

THREE ESSAYS ON ENERGY EFFICIENCY AND ENVIRONMENTAL POLICIES IN CANADA

by

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Dedication

To Amerti, Natai, and Sun

Abstract

This thesis is organized into five Chapters. In Chapter 1, we provide an introduction. In Chapter 2, we present a study on residential energy-efficiency retrofits in Canada. We describe the EnerGuide for Houses data and model household decisions to invest in energy-efficiency retrofits. Our results show that government financial incentives have important positive effects. The decision to invest in energy-efficiency retrofits is positively related to potential energy cost savings and negatively related to the costs of the retrofits. We find that household characteristics such as the age composition of household members are important factors. All else remaining constant, low income households are more likely to undertake energy-efficiency retrofits. In the third Chapter, we present our study on price-induced energy efficiency improvements in Canadian manufacturing. Our study employs a new approach to the estimation of price-induced energy efficiency improvements and the results have important empirical and policy implications. In the fourth chapter, we present our study on the implications of the "shale gas revolution" on Alberta greenhouse gas emission abatement strategy. Given that the strategy is centered on deployment of CCS technologies, we analyze the effects of the declines in natural gas price on CCS deployment in the electricity sector. We use the CIMS simulation model to simulate various policy scenarios under high and low natural gas price assumptions. Comparison of the results shows that CCS market penetration in the electricity sector is very minimal in the low natural gas price scenario

even when a 50% cost subsidy is applied. Accordingly, there is little gain from subsidizing CCS given the "shale gas revolution." We provide a few concluding remarks in Chapter 5.

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Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations, Symbols, and Units

AEO	Annual energy Outlook
AESO	Alberta Electric System Operator
CBEEDAC	Canadian Building Energy End-Use Data and Analysis Centre
CCAF	Climate Change Action Fund
CCS	Carbon Capture and Storage
CIMS	Canadian Integrated Modeling System
CIPEC	Canadian Industry Program for Energy Conservation
CMHC	Canada Mortgage and Housing Corporation
CO2	Carbon Dioxide
CO2e	Carbon Dioxide Equivalent
DHW	Domestic hot water
EGH	EnerGuide for Houses
EIA	Energy Information Adminstration
EOR	Enhanced Oil Recovery

ERCB	Energy and Rsources Conservation Board
GHG	Greenhouse Gas
GJ	Giga Joule
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Clmate Change
KLEMS	Capital, Labour, Energy, Material, and Services
Ktoe	Kilo tonne of oil equivalent
kWh	Kilowatt hour
MBtu	Million British Thermal Unit
MJ	Mega Joule
MKJA	Mark K. Jaccard and Associates
Mt	Million tonne
Mtpa	Million tonnes per annum
MW	Mega Watt
NGCC	Natural Gas Combined Cycle
NRCan	Natural Resources Canada
OEE	Office of Energy Efficiency
PC	Pulverized Coal

PJ	Peta Joule
SMEs	Small and Medium Enterprises
StatCan	Statistics Canada
t	tonne
tcf	Trillion Cubic Feet
UNFCC	United Nations Framework Convention on Climate Change

Chapter 1

Introduction

Concerns about greenhouse gas (GHG) emissions emanate from a generally agreed upon scientific knowledge which predicts severely detrimental long-term effects from concentrations of GHGs in the atmosphere along with the observation that emissions resulting from human activities are substantially increasing these atmospheric concentrations of the GHGs (IPCC, 1990). Carbon dioxide is the most important anthropogenic greenhouse gas whose primary source since the pre-industrial period is fossil fuel use, with land-use change providing another significant but smaller contribution (IPCC, 2005). Hence, tackling the problem of global warming calls for reductions of CO2 emissions which in turn calls for reductions in fossil fuel combustion and possibly the adoption of end-of-the-pipe abatement mechanisms, such as carbon capture and storage (CCS) technologies.[1] Energy efficiency improvements and switching to other clean, renewable energy sources such as wind and solar energy are the main channels for reducing fossil fuel combustion. All of these possible mechanisms for reducing CO2 emissions - energy efficiency improvements, fuel switching, and adoption of end-of-the-pipe abatement techniques -require large scale investments in innovations and adoption of new technologies.

Economic theory, however, suggests that markets fail to address both

[1]In Canada, data from Office of Energy Efficiency (OEE) suggest that both energy consumption and GHG emissions are increasing. Secondary energy use in 2008 was 25% higher than the 1990 levels. Commercial/institutional and total transportation sectors are the ones that experienced the highest growth rates, 39% and 38% higher than 1990 levels, respectively. In the transportation sector, energy consumption in the freight transport sector was over 70% higher. Energy consumption in the industrial sector that accounts for about 39% of the overall energy consumption was about 20% higher than the 1990 level followed by the residential sector (14% higher). As a result, total GHG emission in 2008 was over 22% higher than the 1990 level.

GHG emissions and to induce optimal supply and adoption of new technologies. GHG emissions create an externality in that the producers and consumers (emitters) do not have sufficient economic incentives to internalize the damages caused to the environment. Government policy is, thus, needed to provide the required incentives or regulations.[2] It should be noted that there are various sources of market failures that may deter the market from generating desired levels of innovation and adoption of new technologies, the main mechanisms to attain emission abatements. There are various barriers to innovation and adoption of new technologies. Some of these barriers are related to the unclaimed benefits from innovations and early adoption of new technologies. Others could be related to a lack of information and financial constraints (Jaffe et al., 2005).

Specific to innovations, theory and evidence suggest that the cost of R&D (innovation) and appropriability conditions[3] are among the most important factors affecting the optimal level of R&D (Jaffe et al., 2003). While patents and other forms of intellectual property rights may help to overcome the appropriability problem,[4] financing constraints may call for provision of various financial incentives by the government.

Barriers to to adoption at both the household and firm levels include lack of information, cost or financial constraints, and positive externalities associated with early adoption. Uncertainty associated with adoption of new innovations that have not yet been tried renders an option value from waiting, hence resulting in delayed decisions (Jensen, 1982). More generally, diffusion of a technology often displays an S-shape which depicts that it is slow at an initial stage, followed by a rapid diffusion stage until it slows down again after it reaches maturity (Stoneman, 2002). The main feature is that early adoption is slow due to various constraints. However, an adopter of a new technology creates a positive externality for others in the form of the generation of information about the existence, characteristics, and success of the new technology (Jaffe et al., 2005). As such, the likelihood of technology adoption depends on the rank (whether the

[2] According to the Coase Theorem, allocation of property rights, regardless of to whom the rights are assigned, could resolve market failures to the extent that the parties can easily negotiate and negotiation costs are insignificant. This requires the number of parties involved to be small. However, in reality, several parties are involved making negotiations difficult and costly and, therefore, there is a role for government policy intervention.

[3] Appropriability condition is related to the right to use the innovations exclusively

[4] Efficiency effects of patent rights can be viewed within the context of the famous Coase Theorem.

adopter is the first to adopt or not) and stock (how many people/firms have already adopted the technology) effects (Stoneman and Karshenas, 1993). Baerenklau (2005) underlines that there is an important learning effect generated from agents that have already adopted a technology in their neighborhood. That is, while uncertainties and high costs may deter early adoption, positive externalities created by early adopters would result in more adoption later. Both of these suggest the importance of policy intervention to ease the obstacles to early adoption. Information provision, cost subsidy, and technology standards are all important interventions.

Consistent with this phenomenon, researchers have long observed that households would require shorter pay-back periods (significantly higher individual discount rates relative to the market rate) for investments in energy-using equipment with higher efficiency (Hausman, 1979; Train, 1985). Various engineering-economic studies on energy efficient equipment have also observed that consumers tend to fail to purchase cost-effective energy-efficient equipment on the market (Brown, 2001). Many investments in energy efficiency fail to take place despite their apparent profitability (DeCanio, 1993). Thus, there is an energy-efficiency gap, the difference between the actual level of investment in energy efficiency and the higher level that could be achieved (Sorrell et al., 2004), suggesting existence of untapped energy efficiency improvement potentials. Insufficient and incorrect information is among the most important barriers (Jaffe and Stavins, 1994; Anderson and Newell, 2004). Of course, there are other factors such as split-incentives (principal agent problem), hidden costs, uncertain benefits, and capital market imperfections or limited access to capital (Sorrell et al., 2004; DeCanio, 1993). Evidence shows that all of these factors play important roles in deterring decision to invest in new energy efficient technologies by firms (DeCanio, 1993).

Climate policy interventions can, therefore, be multifaceted. First, government policies to regulate or penalize GHG emissions are required. This could induce various actions towards technical changes as businesses attempt to achieve environmental compliance (Porter and van der Linde, 1995). However, the various barriers and market failures hindering adoption and innovation should be eased through supplementary policies. This may include information provision, subsidies, and technology standards. The key point is that policies have to address both sides of the equation: the incentive to mitigate emissions have to be assisted by various policies to induce innovation and adoption of new technologies. Accordingly, a host of demand side management policies and programs are frequently employed by policy makers in addition to setting emission and technology standards.[5]

The history of climate policy actions in Canada reflects this complexity although some critics maintain that the government focuses too much on the supply and adoption of new technologies through financial incentives, energy efficiency standards, and information provision with no hard emission reduction requirements or penalties such as carbon taxes. This implies that emission reduction is voluntary given all the incentives and information provided (Jaccard et al., 2006). However, the government's actions have been preceded by commitments to cut GHG emissions such that the main rationale for the incentives was to achieve those emission reduction targets. Canada made its first international commitment to cut GHG emissions at the 1988 World Conference on the Changing Atmosphere and then followed this with commitments at the 1988 G7 meeting, the 1992 Earth Summit in Rio and the 1997 negotiation of the Kyoto Protocol (Jaccard et al., 2006).[6] Canada signed an agreement with the (UNFCC) in 1992 to reduce the volume of GHG emissions to 1990 levels by 2000. Moreover, Canada signed the Kyoto protocol in December 2002, committing to reduce GHG emissions by 6% below 1990 levels on average through the first commitment period (2008- 2012) - a reduction of 240 Mt from the projected "business-as-usual" emissions level in 2010.

The Climate Change Action Fund (CCAF) was established in the 1998 Federal Budget with $150 million allocated over three years. The purpose was to promote early action and improve the understanding of climate change in Canada; provide funding for the national process, federal coordination and analysis; technology demonstration and development; public education and outreach; and science, impacts, and adaptation work. The first official business plan, the *Action Plan 2000 on Climate Change*

[5]Demand side management includes providing general and technical information to consumers about how they can better manage their energy consumption; low-interest loans and other subsidies for the installation of energy-efficient technologies; direct or free installation of energy efficient technologies; performance contracting; direct load management; real-time pricing; and market transformation (Loughran adn Kulick, 2005). Information provision could be provided through product labeling or energy efficiency audits

[6]At the invitation of the Government of Canada, over 300 world experts and high level policy makers from 46 countries assembled in Toronto to consider the threats posed by the changing global atmosphere and how they might be addressed(Climate Change Chronology; `http://www.climatechangesask.com/html/learnmore/CanadaInternational/Chronology/index.cfm`).

was unveiled, identifying actions in five broad areas: transportation, housing and commercial/institutional buildings, large industrial emitters, small and medium-sized enterprises, and the international market. More generally, the plan stipulated a five-year, $500-million initiative including the extension of the CCAF. The key targets were general long-term behavioural and technological changes. A subsequent action plan, *Climate Change Plan for Canada* was issued on November 21, 2002 outlining the national strategy to meet the GHG reduction target under the Kyoto Protocol and also announcing additional government funds (Government of Canada, 2005; 2003a; 2003b; 2002; 2000).

Specific to energy consumption and efficiency, the Federal Budget provided $60 million over three years in 1997 (commencing in April 1998) for new initiatives to improve energy efficiency in new commercial buildings, encourage commercial building retrofits, provide for energy performance assessments of houses, and stimulate demand for cost-effective, commercially available renewable energy systems for space and water heating/cooling. Budget 2001 proposed to broaden the eligibility criteria for income tax incentives that apply to renewable energy and certain energy efficiency projects (Government of Canada, 2003a).[7] A 2002 action plan stipulated expansion of cost-shared home energy audits for homeowners, targeting energy efficient retrofits of 20 percent of the housing stock and 20 percent of the commercial/institutional building stock by 2010. This was in addition to actions pertaining to energy efficiency regulations the *Energy Efficiency Act*, which provides for the specification and enforcement of regulations concerning minimum energy performance levels of energy-using products, product labeling, as well as collection of data on energy use. This act was passed by Parliament in 1992 and came into effect in February 1995 (Natural Resource Canada, 1999).[8] The action plan targeted building all new

[7] To encourage production of clean technologies, the 2001 federal budget also introduced a 15-year $260- million production incentive for electricity produced from qualifying wind-energy projects. Tax incentives for renewable were also introduced. Fuel cell and hydrogen technology funding was announced in 2002.

[8] The key objective of the energy efficiency act was to eliminate the least energy-efficient products from the Canadian market. Under the Act, minimum energy efficiency standards were established for some types of energy-consuming products, including appliances imported to Canada or traded between provinces/territories. The regulation was amended in November 1995 to include regulation of general service fluorescent lamps and general service incandescent reflector lamps; in November 1997 to strengthen and clarify the regulations as they apply to electric motors and to simplify administrative requirements for motor dealers; and in December 1998 to introduce minimum energy efficiency standards for 15 energy-using product and to increase the existing energy efficiency standards for two products (Natural Resource Canada,

homes to an R-2000[9] or equivalent standard by 2010 and all new commercial/ institutional buildings to a minimum of 25 percent above the *Model National Energy Code* by 2010 (Government of Canada, 2003a, 2002). In the industry sector, the action plan stipulates increased actions through the Canadian Industry Program for Energy Conservation (CIPEC) via cost-shared energy efficiency audits and expanding its scope to include Small and Medium-Sized Enterprises (SMEs). Other action plan aspects included promoting Energy Star products,[10] and public awareness about the need and methods for becoming involved by emphasizing the Kyoto commitment through a one-ton GHG reduction challenge for each citizen.

A residential energy audit program known as the EnerGuide for Houses (EGH) was put in place in 1997. The EGH program involved a home energy evaluation including tests to find air leakages and determine the energy efficiency of the heating system. In its early implementation, the EGH program mainly focused on information provision pertaining to energy efficiency improvement potentials. In August, 2003, the government announced the EGH grant program to encourage homeowners to participate in the program that had been ongoing without federal financial assistance.[11] The size of the financial incentive was based on the difference in the EGH energy efficiency ratings before and after upgrades were implemented, to a maximum of $3,348.

Generally, the 2002 action plan reflects Canada's concerns with competitive disadvantages resulting from the US decision not to sign the Kyoto protocol. Hence, the government emphasized the use of various financial incentive packages and energy efficiency regulations stated above. At about the same time, the government also set a course to begin examining Carbon Capture and Storage (CCS) potentials (Government of Canada, 2002).

1999).

[9] The R-2000 Standard includes requirements related to energy efficiency, indoor air quality and the use of environmentally responsible products and materials. See `http://oee.nrcan.gc.ca/residential/personal/new-homes/r-2000/standard/current/purpose.cfm?attr=12`

[10] Energy Star is the international symbol of premium energy efficiency and its use is monitored in Canada by Natural Resources Canada's (NRCan's) Office of Energy Efficiency (OEE); see `http://oee.nrcan.gc.ca/residential/business/energystar/index.cfm?attr=12`

[11] The EGH program (for existing houses) should not be confused with the EnerGuide labeling Program that was first introduced in 1978 as part of the Consumer Packaging and Labeling Act, primarily used for energy-efficiency ratings of appliances, heating and cooling equipment, houses and vehicles. There was also a program known as EnerGuide for New Houses program which was introduced in 2006.

During the same year, the Alberta Government also issued its climate action plan (Government of Alberta, 2002) indicating its plan to explore CCS potentials. Recently, the federal government along with governments of Alberta and Saskatchewan have allocated significant financial incentives to CCS projects.

These various government actions that aim at GHG emission reductions form the basis for the research questions we tackle in this dissertation. Policies are likely to be more effective when applied with a clear understanding of how the target group responds to various incentives given various economic, demographic, and other factors. For example, financial incentives provided for residential retrofit investments may be ineffective in terms of inducing the investments if not properly targeted. Understanding how households of different income and demographic structures have responded to previous incentives can inform future policy makers in important ways. This forms the main thesis in the first paper (Chapter 2). We model residential retrofit investment behaviour using the EGH audit data that were compiled during the first and the second audits of program participants. From October 1998 to December 2005, over 188, 000 houses underwent first audits under the EGH program of which nearly 20 percent were known to have undertaken at least some of the recommended energy-efficiency retrofit investments, as they underwent a second audit that was used to validate the actions in order to apply for government rebates. Our findings suggest that while financial incentives appear to have significant positive effects on retrofit investments, there is also important variation based on income and demographic structures. We observe significant increase in both participation in the first audit as well as the probability to undertake retrofit after the government introduced financial rebates. Retrofit investment is negatively related to costs and positively related to potential energy cost savings from the investments. We also find that low income households are more likely to undertake retrofits suggesting that financial incentives targeting low income group could render the program to have better impacts.

One of the possible mechanisms to induce efficiency improvements in order to reduce GHG emissions in the industrial sector is the use of a fuel tax which has a direct effect on increasing energy costs. There is evidence suggesting the existence of a relationship between energy prices and energy saving innovations or efficiency improvements (Popp, 2002; 2001). The second paper (Chapter 3) seeks to identify price-induced energy efficiency improvements in Canadian Manufacturing, separating out the impacts of forecasted and realized energy prices. We model price induced efficiency improvements by noting that efficiency improvement in many manufacturing industries is a result of adoption of energy efficiency equipment. As noted by (Newell et al., 2006), a natural way to model induced technical change is to recognize that energy-saving technological change comes about largely through the introduction of new capital goods that embody improved energy efficiency; that is, lower energy requirements per unit of output. Thus, we posit that business investment in efficiency can be viewed as investment decisions regarding equipment embodying energy efficiency and such investments are based on discounted present value calculations. In this way, expected energy price, as a key determinant of the value of expected energy cost savings must be considered in the decision making process. That is, businesses base their energy efficiency investments partly on expected energy prices. We note that forecast energy prices that are used for such business decisions are only weakly correlated with actual energy prices, an observation vital for estimation of separate substitution and efficiency-inducement effects of energy price changes. To our knowledge, our study is the first to isolate these distinct effects of energy prices using such methodology. Our results support the existence of price-induced efficiency improvements in general. We also show that a failure to account for price-induced energy efficiency effects may result in erroneous estimates of substitution effects. This is important contribution to the literature in the light of the difficulties in estimating the two distinct effects of energy price changes in the literature (e.g. Linn, 2008; Kaufmann, 2004; Sue Wing, 2008). Moreover, with the more recent recognition of existence of induced technical change in economic models of climate policy analysis (e.g. Popp, 2004), empirical estimation of price-induced efficiency improvements can play a very important role in climate policy modeling and analysis.

In the final paper (Chapter 4), we assess the implication of the "Shale Gas Revolution" for the Alberta CCS strategy. Recently, Canada's federal and provincial governments have committed a total of approximately $3 billion in funding for CCS. The objective is is to support three to five large-scale CCS demonstration projects through the federal Clean Energy Fund, ecoENERGY Technology Initiative, and the Sustainable Development Technology Fund (Natural Resource Canada, 2009). Alberta alone allocated a $2 billion Carbon Capture and Storage Fund to be used to finance CCS projects through a government - private sector partnership (Government of Alberta, 2009). The objective is to achieve widespread deployment of CCS in order to achieve significant GHG emission reductions. Meanwhile, technological breakthroughs in horizontal drilling, known as hydraulic fracturing, has resulted in a substantial increase in the supply of unconventional natural gas in North America. This has led to a significant drop in natural gas prices. This has significant impacts on the attractiveness of CCS relative to other GHG abatement strategies compared to a world with perviously forecasted high natural gas prices. Using the Canadian Integrated Modeling System (CIMS) simulation model, we compare and contrast market penetration of CCS in the electricity sector under various policy scenarios, including a 50% cost subsidy. We compare and contrast results under high and low natural gas price scenarios. We find that CCS market penetration is significantly constrained with the new low natural gas prices even when a 50% cost subsidy is applied. We conclude that that CCS subsidy is not a viable policy tool for Alberta under the new natural gas market conditions.

The thesis concludes with a few closing remarks in Chapter 5.

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Chapter 2

An Explanation of the Probabilities and Intensities of Residential Energy-Efficiency Retrofits in Canada

2.1 Introduction

The introduction, in April 1998, of the EnerGuide for Houses (EGH) home energy efficiency audit program as a mechanism for promoting energy efficiency is rooted in the observation that residential home retrofits offer great potential for energy saving and hence for the reduction of GHG emissions.[1] Generally, home energy audits provide an important mechanism for informing homeowners about their current energy usage and wastage, as well as available energy-savings options. Deutscher and Munro (1980) argue that home energy audits provide a vital tool to help homeowners decide to undertake beneficial retrofits since the most important barrier to making such decisions is a lack of information and uncertainties surrounding the alternatives and the resulting cost savings.

Specific to Canada, Jaccard et al. (2002) argue that about 46 percent of the Canadian GHG emission reductions commitment for the residential sector under Kyoto could be achieved through retrofitting building shells and furnace improvements. They note that the stock of houses built before 1980, when many of energy conservation programs started, represents 70

[1]According to the Natural Resource Canada's (NRCan) Office of Energy Efficiency, the residential sector is the third largest both in terms of energy consumption and greenhouse gas (GHG) emissions. Space heating, ventilation, air conditioning and cooling (HVAC) account for over 60 percent of energy use and 50 percent of the GHG emissions by the residential energy sector **?**.

percent of the current total housing stock. This cohort of houses built before 1980 tend to be about 25-40% less energy efficient as compared to R2000 and, therefore, use 30 percent more energy than homes built to the R2000 standard (Sadler, 2003).[2] Yet, a survey eliciting information on residential retrofits conducted in 1994 shows that only about one in twenty homeowner households undertook major work (improved insulation and improvements to windows and doors) aimed at improved energy efficiency (NRCan, 1997).[3]

In this study, we seek to explain home owners' retrofit decisions in the context of the EGH program to highlight the major underlying factors. By doing so, we will attempt to identify whether government financial rebates induce retrofit investments in general and what types of households are more likely to retrofit, controlling for other relevant variables.

The EGH program, which was terminated on May 12, 2006, was developed by the office of energy efficiency (OEE) of NRCan in cooperation with Canada Mortgage and Housing Corporation (CMHC) to provide evaluation services to homeowners with information on energy-efficiency improvements for their homes (Natural Resource Canada, 2005a).[4] In simple terms, it was a home energy audit program which, in some years, was combined with a financial incentive package. The Government of Canada allocated $73.4 million dollars in Fall 2003 to EGH retrofit incentives. The EGH home retrofit program proved to be so popular that the 2005 Federal budget announced an increase in incentive funding by $225 million over five years to encourage up to half a million homeowners to increase the energy efficiency of their homes (Natural Resource Canada, 2005b; Finance Canada, 2005).

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[2] The R-2000 Standard (R-2000) is an industry-endorsed technical performance standard for energy efficiency, indoor air tightness quality, and environmental responsibility in home construction. It was officially launched in 1982. For background and description, see `http://oee.nrcan.gc.ca/residential/personal/new-homes/r-2000/background.cfm?attr=4`.

[3] Building energy retrofits are of great significance not only because there are widespread energy efficiency gaps in the buildings sector, but also due to the often low upfront costs (Jacoby, 2004). In addition to their energy saving role, home retrofits also have ancillary benefits in the form of improved thermal comfort (Clinch and Healy, 2003). Conservation through retrofits does not involve major adjustments to household lifestyles, and offers potential economic returns to the consumer (Deutscher and Munro, 1980) .

[4] Homeowners who completed the first assessment by May 2006 had until March 31, 2007 to complete the final assessment and apply for the grant. The ecoENERGY Retrofit program, which ended March 31, 2011, was launched on April 1, 2007 as a replacement for the EGH program.

The Government of Canada provided, during the 2003 - 2005 period included in our data set, grants to homeowners who completed energy efficiency retrofits based on recommendations of an EGH adviser as an incentive for undertaking the recommended retrofit actions. The grant amount was determined based on the difference between the pre- and post-retrofit EGH ratings of the houses. Only homes evaluated using the EGH service were eligible for these government grants. Thus, homeowners had to request that EGH auditors conduct a second round assessment to determine that a minimum level of energy efficiency improvements had been achieved in order to qualify for government grants.

For homeowners able to demonstrate at least a minimally acceptable improvement in the energy efficiency of their homes, the amounts of the corresponding grant ranged between \$116 and \$3,348. Another incentive package was offered by Canada Mortgage and Housing Corporation (CMHC) as a 10 percent refund on mortgage loan insurance premiums for homeowners who borrow money to build or buy an energy–efficient home or renovate an existing one. Starting from January 1, 2005, home buyers also had the flexibility of extending the amount of time required to repay their mortgage from 25 years to a maximum of 35 years.

Our objective is to carry out an empirical analysis aiming to address this question. We begin by providing a descriptive analysis that sheds light on the heating system and house characteristics of Canadian residential dwellings, and the upgrade recommendations that were made for the homes that were audited. In our formal analysis, we model residential retrofits as being the outcome of a two-step process in which homeowners first decide whether to undertake a retrofit investment, and then decide as to which specific upgrade types to undertake. We emphasize the roles of expected energy savings (as measured by upgrade case energy cost saving computed during the first audit), the investment costs, and government rebates, given various heating system equipment types and efficiency characteristics, thermal efficiency properties of the homes, and household characteristics such as income and education.

Our results suggest that financial incentives can play an important role, as evidenced by the statistically significant positive effects of energy costs saving potentials and indicators of government incentives on both the probability and the intensity of retrofits. We also find that the costs of retrofits have negative impacts on retrofit investments. Household characteristics such as income, household size, age composition, and average education levels appear to play important roles as as well. The fact that income appears to have negative effects suggests that policy makers may need to target low income homeowners for better results.

The remainder of the paper is organized as follows: Section 2.2 provides a description of the EGH data. Section 2.3 provides an overview of the related literature. This is followed by a discussion of modeling and estimation issues in Section 2.4. Estimation results are provided in Section 2.5. Section 2.6 concludes.

2.2 Description of EGH Data

The EGH Audit Report

The EGH program was introduced in April 1998, with the data set indicating that homeowners started ordering their first audits in October 1998. A financial incentive program was announced in October 2003 to provide further motivation to improve energy efficiency. The amount of the incentive is based on the difference in the EGH energy efficiency ratings before and after upgrades are implemented. The greater the improvement in the rating, the larger the incentive, to a maximum of $3,348 (Natural Resources Canada, 2005a; Blais et al, 2005; Aydinalp et al., 2001).

The EGH audit reports submitted to NRCan have resulted in a rich data set which contains the information compiled during both the first and, if undertaken, the second audits. For the initial assessment, the first audit reports provide estimates of pre-retrofit and upgrade case energy consumption and costs by energy type.[5] They also provide details of the actual thermal properties of the buildings and HVAC system along with a list of recommended upgrades. The report that is provided to the homeowner includes specifics regarding the amount of energy loss through basements, windows, doors, main walls, ceilings, before and after recommended retrofits. If the homeowners undertake sufficient upgrades they may decide to pay for a follow-up energy audit. During both audits, the following

[5] The audits are conducted by independent professionals certified by the Office of Energy Efficiency (OEE).

details of the audited houses are recorded:[6]

1. General information: Construction year - City, weather location (more than one city or towns may belong to the same weather location), province, Number of occupants, Basement and main floor temperatures (ºC)

2. Construction characteristics: House volume (m^3), heated area (m^2), and footprint (m^2); house type, number of floors, house shape; ceiling, foundation wall, and main wall insulation values (RSI); air change rate at 50 Pa; leakage area (cm^2); and Critical month natural and total air change per hour

3. Equipment stock: Space and domestic hot water (DHW) heating equipment type, efficiency, and fuel type; and Central ventilation type

4. Estimated energy consumption and costs: Annual electricity (kWh), natural gas (m^3), and oil consumption (L); annual total household and space heating energy consumption (MJ); Annual electricity, natural gas, oil, and total energy costs ($)

5. Calculated heat losses: Air, basement, roof, wall, and window heat losses (MJ)

6. EnerGuide Rating (see Table 1 for a general guide to the EGH ratings)

From the first audit, each house is assigned an EGH rating which summarizes the dwelling's' energy efficiency characteristics (See Table 2.1 for ranges of the EGH ratings). The calculation of the EGH energy consumption and EGH ratings are based on standard operating conditions in order to compare similar houses in the same regions. The basic assumptions are: 1) Total minimum monthly ventilation rate of 0.30 ACH (air change rate/hour)during the heating season (October through April), including both natural and mechanical ventilation; 2) four occupants (2 adults and 2 children) present in the house 50% of the time; 3) Electrical consumption (lights and appliances) of 24 kWh per day or 8760 kWh/year; 4) Temperature set point of 21°C on main floors and 19°C in the basement; 5) Consumption of 225 liters of hot water per day; and 6) 30 year average

[6]See Appendix II for an example of a full audit report.

Table 2.1: Summary of the EGH Home Energy Efficiency Rating System

Household Characteristics	Typical Rating
Older house not upgraded	0 to 50
Upgraded older houses	51 to 65
Energy-efficient upgraded older house or typical new house	66 to 74
Energy-efficient new house	75 to 79
Highly energy-efficient new house	80 to 90
House requiring little or no purchased energy	91 to 100

Source NRCan/OEE; `http://oee.nrcan.gc.ca/residential/personal/home-improvement/service/rating.cfm?attr=4`

weather data.

Each house audited receives a checklist of upgrade recommendations pertaining to the thermal envelope (upgrade case ceiling, foundation wall, and main wall insulation values (RSI) and air change rate at 50 Pa); recommended retrofits for equipment stock (upgrade case space and DHW heating equipment type, efficiency, and fuel type); the implied estimates for energy consumption and costs after the recommended retrofits (annual electricity (kWh), natural gas (m3), oil (L), and total household energy (MJ) consumption and costs ($); upgrade case heat losses (air, basement, roof, wall, and window heat losses (MJ); and the anticipated EnerGuide Rating after completion of the recommended retrofits.

Descriptive Analysis

We observe that only about 19% of the houses undergoing a first audit are observed to implement the recommendations. Part of the explanation is related to the nature of the data themselves. That is, our data have a cut-off date, which means there could be homeowners that had actually undertaken the recommended retrofits but were yet to order the second audit or there could be households that had undergone the first audit only a few months before the cut-off date. This is important because there is a time gap permitted between the date of first and second audits in order for homeowners to implement all or some of the recommendations in order to qualify for the grant. Homeowners whose first EGH audit was conducted prior to August 12, 2003 had until October 15, 2004 to complete their second evaluation and have their application received. Homeowners who had their first evaluation after August 12, 2003, had 18 months from the date of their first audit to complete their second evaluation and submit their application to qualify for the grant. Thus, by September 2005, the cut-off date for our data, there could be homeowners that were still eligible to undergo a second audit and apply for rebates.

The EGH data set used here includes 188,368 houses from across Canada that had undergone a first EGH audit between October 1998 and September 2005. About 33% of these houses underwent a first EGH audit before October 2003, when the government introduced rebate grants.[7]

As shown in Table 2.2, approximately 32% of the houses that underwent a first EGH evaluation are in Ontario; 19% in Alberta, and 17% in British Columbia. The fourth largest uptake in initial audits was in Quebec (12%), with the remaining provinces and regions accounting for 20%.

As shown in Table 2.2, less than 20% of homeowners (over 35,000 houses) who undertook the first audit also completed the second evaluation by the end of 2005. With the introduction of incentives in October 2003, we observe that the number of houses that underwent the first audit jumped significantly, such that 2004 was characterized by the the largest number of first audits (Table 2.3).

As the last two columns of Table 2.2 show, there is a quite marked variation across regions in terms of the percentage of homes participating in the second audit. The largest proportions of houses undergoing second audits are again in Ontario, Alberta, and British Columbia, which together account for 73%. However, there is a quite different pattern across provinces and regions in terms of the proportion of houses from the first audit that also undertook the second evaluation. Quebec has the highest proportion at 27.2%, while Alberta and Manitoba have around 22% each, followed by British Columbia with 19.8% and Ontario and New Brunswick both at 18.8%. Variation in the cost of auditing and the fact that auditing service is subsidized in some provinces could contribute to the regional variation, among other factors.[8]

[7] See table 2.10 for related information

[8] In the econometrically modeling the retrofit decisions, such province and territory-

Table 2.2: Number of Homes in the First and Second EGH Audits by Province

House Region	Number of Homes in the first audit	Percent of total	Number of Homes in the Second Audit	Homes in the Second Audit as a percent of the number in the first audit	Homes in the Second Audit as a percent of the Total Number of Homes in the second audit
British Columbia	32647	17.3	6461	19.8	18
Alberta	34798	18.5	7927	22.8	22
Saskatchewan	13823	7.3	3756	10.64	11
Manitoba	12668	6.7	2782	22.0	8
Ontario	60448	32.1	11344	18.8	32
Quebec	22114	11.7	1580	27.2	4
New Brunswick	1781	.9	334	18.8	1
Nova Scotia	5326	2.8	696	13.1	2
Newfoundland	2089	1.1	187	9.0	1
Prince Edward Island	533	.3	41	7.7	0
Nunavut	64	.0	0	0	0
Northwest Territory	364	.2	30	8.2	0
Yukon Territory	1713	.9	151	8.8	0
Total	188368	100.0	35289	18.7	

There are a number of possible reasons for the relatively low participation rate in the second audit. First, it is possible that many of the homeowners were planning to have a second audit but had not yet done so. Second, the grants were only available for a specific period – retrofits and second audit generally had to be completed within 18 months of the first audit. This deadline may have proved too short a period for some homeowners or may not yet have expired for some homeowners. Third, homeowners may not have undergone a second audit even though the recommended retrofits were undertaken. This could occur because the second phase EGH auditor's service involves service charges, and homeowners may not consider a second audit to be worthwhile if the expected grant amount is small. This is perhaps more likely for newer houses where the efficiency

specific factors are captured by dummy variables.

Table 2.3: First Audits by Year of Audit and House Region

	House Region													
Year of first Audit	BC	AB	SK	MB	ON	QC	NB	NS	NF	PEI	NU	NT	YK	Total
1998	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	240 (0.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	240 (0.1)
1999	4816 (14.8)	621 (1.8)	143 (1.0)	516 (4.1)	2220 (3.7)	333 (1.5)	12 (0.7)	79 (1.5)	40 (1.9)	6 (1.1)	0 (0.0)	2 (0.6)	135 (7.9)	8923 (4.7)
2000	3702 (11.3)	2110 (6.1)	1069 (7.7)	722 (5.7)	3110 (5.1)	306 (1.4)	0 (0.0)	429 (8.1)	190 (9.1)	1 (0.2)	0 (0.0)	1 (0.3)	154 (9.0)	11794 (6.3)
2001	3235 (9.9)	267 (0.8)	1128 (8.2)	551 (4.3)	3330 (5.5)	733 (3.3)	16 (0.9)	377 (7.1)	371 (17.8)	2 (0.4)	0 (0.0)	1 (0.3)	122 (7.1)	10133 (5.4)
2002	3493 (10.7)	2212 (6.4)	1597 (11.6)	781 (6.2)	4716 (7.8)	828 (3.7)	81 (4.5)	399 (7.5)	515 (24.7)	21 (3.9)	49 (71.0)	0 (0.0)	126 (7.3)	14818 (7.9)
2003	4973 (15.2)	4710 (13.5)	3173 (23.0)	1381 (10.9)	9025 (14.9)	2273 (10.3)	278 (15.6)	793 (14.9)	211 (10.1)	49 (9.2)	20 (29.0)	115 (31.8)	766 (44.7)	27767 (14.7)
2004	6313 (19.3)	18158 (52.2)	4645 (33.6)	6009 (47.4)	22271 (36.8)	6890 (31.2)	882 (49.5)	1674 (31.4)	337 (16.1)	297 (55.7)	0 (0.0)	166 (45.9)	289 (16.9)	67931 (36.1)
2005	6110 (18.7)	6722 (19.3)	2068 (15.0)	2708 (21.4)	15532 (25.7)	10751 (48.6)	514 (28.8)	1576 (29.6)	424 (20.3)	157 (29.5)	0 (0.0)	77 (21.3)	123 (7.2)	46762 (24.8)
Total	32642	34800	13823	12668	60444	22114	1783	5327	2088	533	69	362	1715	188368

Note: Values in brackets are percentages of column total

ratings may not significantly increase after the upgrades. Finally, homeowners many not implement many of the recommended retrofits. In order to obtain an accurate explanation of non-participation in the second audit it is necessary to explore the EGH data in some detail.

Characteristics of Homes in the EGH program

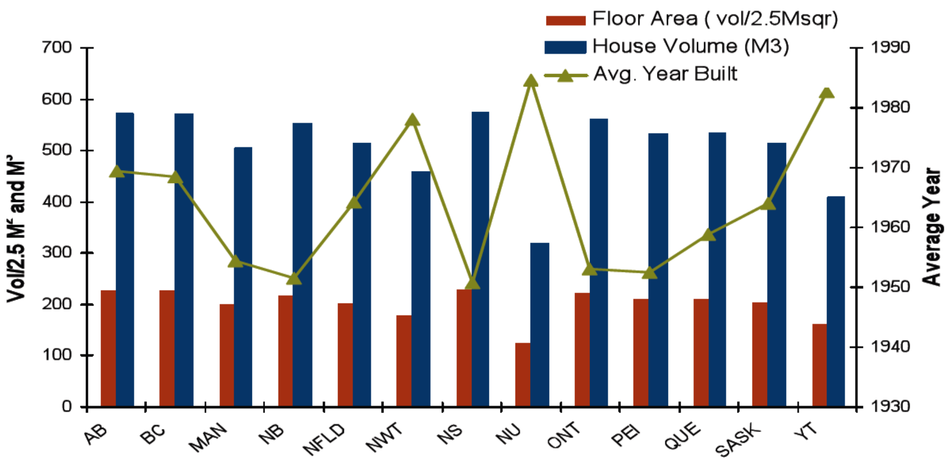
Part of the variation observed in retrofit decisions across provinces could be attributable to variations in house characteristics. Table 2.4 shows that the large majority of the homes in the EGH program are older. About 94% of the houses participating in the program were built in 1990 or earlier, with houses built before 1971 accounting for 55 % of the participants. Over 90% of the houses in the sample are single detached houses. About 46 percent of these are one floor while 46 percent are two floor buildings.

There is marked variation in the average ages of the homes across the provinces (Figure 1.1). On average, the most recent participating buildings are in Nunavut, Yukon and Northwest Territories while the oldest ones are in Nova Scotia and New Brunswick. While there is not much variation in

Table 2.4: Age Distribution of the Houses

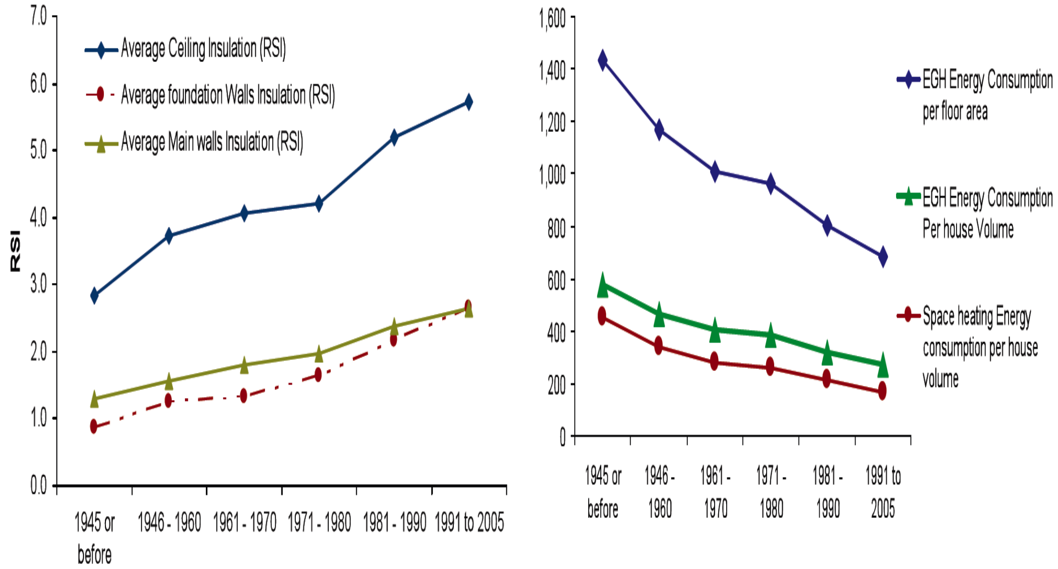
Year Built	Frequency	Percent	Cumulative Percent
1945 or before	37563	19.9	19.9
1946 to 1960	35575	18.9	38.8
1961 to 1970	30409	16.1	55.0
1971 to 1980	46561	24.7	79.7
1981 to 1990	26369	14.0	93.7
1991 to 2005	11891	6.3	100.0
Total	188368	100.0	

Figure 2.1: House Sizes, and Years of Construction by Province and Territory



the average sizes of the buildings as described by the floor area and house volume across most regions, we observe that the territories, are also characterized by smaller home sizes. This is important because home heating which is directly dependent upon the house volume is the most important component of residential energy consumption. The fact that older houses in the data set tend to have larger floor areas would tend to make energy consumption by old homes much higher than that of the newer homes. To the extent that this is the case, there would be great potential for the (predominately older) houses involved in the initial assessment to increase their energy efficiency by undertaking the recommended retrofits. Of course this assumes that other factors such as heating-degree days are the same. Despite being newer and having smaller floor areas, energy consumption could be higher in typical houses in Nunavut, Yukon and the Northwest Territories as they experience more heating-degree days.

Figure 2.2: Thermal Insulation and energy intensity



Thermal characteristics of the houses

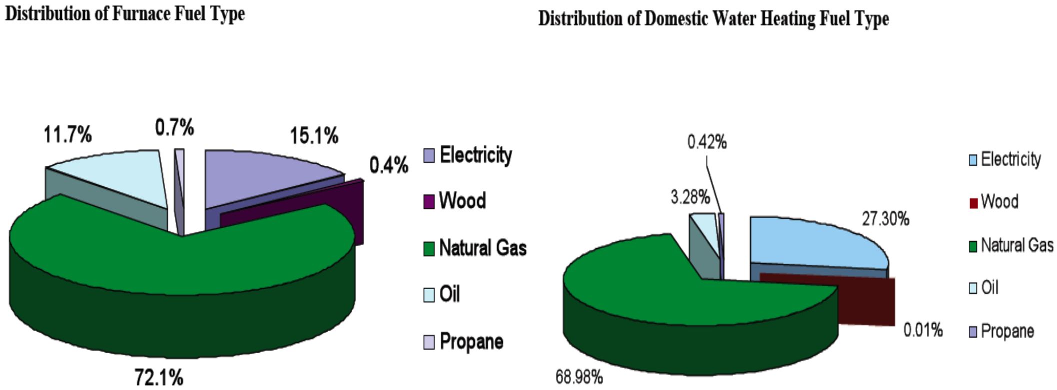
Thermal conditions of buildings, and hence their energy intensities appear to be highly dependent upon the ages of the buildings. Figure 2.2 shows that newer buildings have better average levels of ceiling and wall insulation. Poor thermal insulation implies heat loss which can result in larger energy intensity.

Furnace and Domestic Hot Water (DHW) System and Fuel Types

Energy consumption patterns depend on the types of equipment used. In the EGH database, furnaces with continuous pilots are used in more than 45% of the cases. This indicates that for program participants natural gas is the most widely used energy source for space heating. Electric baseboard heaters are used in 12% of the cases (mainly in Quebec). This suggests that electricity is the second most widely used form of energy for space heating among participants, and is foremost in Quebec. The furnace fuel type data, Figure 2.3, shows that natural gas is the furnace fuel used in more than 72 percent of the cases, followed by electricity (15 %) and oil (12 (%). Propane and wood are used by only 1% of the participants.

Variations in furnace types can contribute to variation in energy efficiency. High efficiency baseboards, forced air furnaces, radiant ceiling

Figure 2.3: Fuel Types used for Furnace and Domestic Hot Water Heating



panels and radiant floor panels can be 100 percent efficient while wood furnaces, and conventional furnaces and boilers can be highly inefficient. This suggests that there are potentially significant gains from upgrading the heating system from less efficient to the most efficient specifications.

The DHW system type that is most common among participants is a conventional tank and conventional tank (pilot), with 90 percent of the participating households using this system type. The DHW fuel type is also dominated by the use of natural gas (about 69%). However, there is more widespread use of electricity for domestic water heating compared to home heating, while there is less widespread use of oil for this purpose compared to the home heating (Figure 2.3).

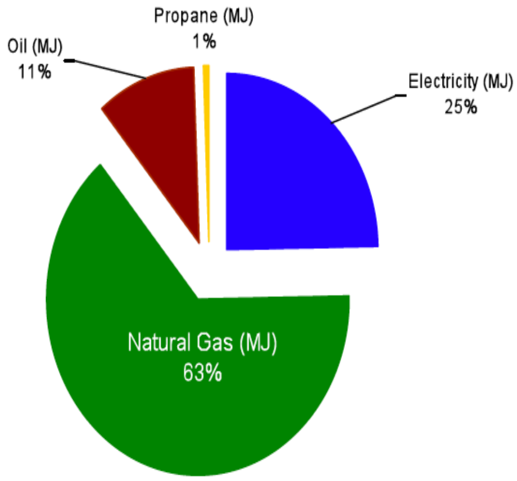
Overall, energy consumption patterns are such that natural gas accounts for about 64% of total energy use while electricity, propane and oil account for 25%, 10%, and 1%, respectively (Figure 2.4). This general pattern is not sensitive to the ages of the buildings. Comparing the two main fuel uses, we find that about 72% of energy consumption is for heating purposes. This proportion is as high as 78% in New Brunswick and as low as 58 percent in Nunavut.[9]

Upgrade Recommendations

All initial audits resulted in at least one upgrade recommendation. Undertaking renovations to reduce air leakages (air sealing) was recommended for all houses (Table 2.5). Window and door upgrades were rec-

[9]The proportion we broadly classified as DHW energy comprises all energy uses other than for the purposes of heating the homes.

Figure 2.4: EGH household energy consumption patterns



ommended for 75% of the houses audited whereas foundation wall insulation upgrades were recommended for 63% of the houses. Heating system upgrades (furnaces, boilers, heat pump, and water heaters) were recommended for over 61% of the houses audited. Main wall insulation was, however, recommended for less than 50% of the houses audited. Exposed floor insulation was recommended in 6% of the cases (Table 2.5).

There is regional variation in the distribution of upgrade recommendations. In British Columbia, Alberta, and Saskatchewan, for example, most houses received upgrade recommendation to upgrade their heating systems. Natural gas is the main fuel type used in these provinces and upgrading furnaces to newer medium to high efficiency standards was recommended. Ceiling insulation upgrades were less likely to be recommended in Saskatchewan and Nunavut. Main wall insulation improvements were recommended for most houses in Alberta, New Brunswick, Newfoundland, the Northwest Territories, and Saskatchewan, whereas foundation wall insulation upgrades were more likely to be recommended in most regions with the exception of the territories. Nova Scotia is the leader in terms of the percentage of houses recommended to upgrade exposed floor insulation. Most houses were recommended to undergo window and door upgrades, with percentages as high as 95% in Alberta and 91% in Saskatchewan. However, Quebec stands out with less than 50% houses recommended for this particular upgrade, followed by Nunavut (36%).

Generally, houses with more inefficiency problems were recommended to undergo more upgrades. As shown in Table 2.6, the average number of upgrade types recommended for older homes built are larger, in general.

Table 2.5: Recommended Upgrade Types (%)

House Region	Air leakage (air sealing based on blower door comparison)	Heating system (furnace/ boiler, heat pump, and water heater)	Ceiling insulation	Main Wall insulation	Foundation wall insulation	Exposed floor area upgrade	Window and door upgrade
BC	100	69.58	53.89	34.77	48.97	4.7	82.11
AB	100	91.18	66.61	60.72	62.06	3.47	95.48
SK	100	77.97	49.08	60.82	63.06	7.96	91.12
MB	100	73.78	69.54	41.60	75.04	4.7	57.48
ON	100	59.04	58.54	33.87	67.24	7.65	68.70
QC	100	11.22	62.02	32.41	63.34	4.49	49.37
NB	100	26.47	74.59	57.38	82.73	9.98	74.26
NS	100	25.81	70.57	45.37	73.12	12.86	72.48
NF	100	12.98	62.79	58.62	72.89	8.19	63.46
PEI	100	26.64	69.61	37.34	77.86	7.69	57.97
NU	100	15.94	13.04	36.23	0.00	0.00	36.23
NT	100	35.91	49.72	62.71	35.08	2.49	64.36
YK	100	21.63	57.32	39.42	42.80	5.60	71.14
All	100	61.32	60.20	42.25	62.97	5.97	74.67

Table 2.6: Number of Upgrade Recommendations by House Vintage

Decade Built	Total Number of Upgrades 1	2	3	4	5	6	7	8	9	Average
≤1900	186	1015	3018	3761	2438	475	93	41	1	3.84
1910	60	431	1472	2252	2122	350	26	16	0	4.07
1920	85	609	1966	2837	2253	450	23	4	0	3.98
1930	67	419	1267	1867	1461	208	17	8	0	3.93
1940	127	919	2820	3818	2958	342	27	13	0	3.89
1950	363	2140	6366	9130	7059	644	59	19	0	3.88
1960	442	2787	7561	10439	7817	782	89	20	1	3.84
1970	894	4627	12510	16550	10764	1127	110	39	2	3.77
1980	1313	4974	9545	9115	3910	457	64	8	1	3.37
1990	1722	3256	3622	2349	674	86	18	0	1	2.77
2000	640	893	704	275	67	8	2	1	0	2.33
Total	5899	22070	50851	62393	41523	4929	528	169	6	3.69

This matches with our earlier observation than older houses are characterized by larger energy intensities, and poor efficiency characteristics in general. About a third, were recommended to undergo four different types of upgrades. Relatively, few were advised to undertake more than five upgrades.

Second Audit Participation

Although all of the houses that underwent a first audit were provided with upgrade recommendations by the energy auditors, homeowners could undertake as few or as many of the recommendations as they wished. The size of any grant that they might receive following the second audit depended on the potential amount of energy saving that the second audit revealed.[10] Only about 18.7 percent of initial participants undertook a second EGH audit. Although some households may have declined the second audit despite following through on recommended retrofits, only households that completed the second audit are *known* to have undertaken at least some of the recommended actions. One of the most important questions

[10]Energy saving in the audits in the audits are based on engineering calculations and do not take into account any effects of behavioural factors (such as rebound effects).

is, therefore, what characteristics do these homeowners have compared to other observable households.

First, a comparison of the regional shares in the first and second phases of the audits (Table 2.2) reveals that there are regional disparities in the tendency to participate in the second audit. The shares of houses in the second audit in the western provinces are higher than their first phase counterparts. On the other hand, smaller shares, as compared to the first audits, were observed in the eastern and Atlantic provinces (Table 2.2). This disparity can be attributed to a number of factors including regional variation in the costs of the EGH audit services due to the presence of provincial subsidies. For example, the Newfoundland and Labrador government's energy rebate program provides $300 toward the cost of a complete home energy efficiency audit.[11] Regional variation in the distribution of house ages could be another factor. Furthermore, variation in the distribution of the heating system and fuel types could be another possible explanation since some heating systems are more efficient than others and energy efficiency conditions are expected to be a key factor behind a homeowner's decision to undertake the recommended upgrades.

Focusing on the homes with second audits, we observe that houses with greater energy saving potential are more likely to undertake retrofit upgrades, and that the higher is the energy-saving potential, the greater is the number of upgrades chosen. In particular, a poor initial EGH rating generally corresponds to a larger number of retrofit upgrades being undertaken, while larger ratios of pre-retrofit to post-retrofit energy consumption and cost (indicators of energy consumption and cost saving potential) generally correspond to homeowners undertaking more upgrades (Table 2.7). A higher retrofit intensity (number of various types of upgrades) also tends to vary along with measures of pre-retrofit blower door air leakage (a measure of how air-tight the homes are).

This feature of the data, whereby houses with a greater energy saving potential are more likely to undertake retrofit upgrades, is also apparent when we compare houses that underwent both audits with those who did not. As Figure 2.5 shows, houses that underwent both audits (underwent some energy-saving retrofits) are generally characterized by higher pre-upgrade average overall and space heating energy intensities. This also

[11] http://www.nr.gov.nl.ca/savingenergy/pdf/nlenerguideprogramguide.pdf

Table 2.7: Upgrade Intensity and its Determinants

Total Number of Upgrades	EGH Rating at first Audit	Energy Consumption Ratio (A/B)	Energy cost Ratio (A/B)	Blower Door ACH @ 50Pa Ratio (A/B)
1	61.9	1.15	1.16	1.22
2	59.7	1.26	1.19	1.15
3	57.3	1.32	1.22	1.21
4	54.4	1.44	1.30	1.28
5	50.4	1.60	1.42	1.40
6	45.2	1.87	1.57	1.55
7	39.7	2.19	1.70	1.60
8	32.7	2.49	2.00	2.02

A and B stand for pre-upgrade and post-upgrade, respectively.

suggests that the larger the energy and cost saving potential, the higher is the probability that a homeowner will invest in retrofitting. Similarly, it also suggests that anticipated energy savings is one of the main drivers of retrofit upgrades.

High energy intensity is largely the result of poor thermal envelope conditions and low-efficiency heating systems. Figure 2.6 shows that these underlying factors also distinctly characterize the two groups of homeowners - those who undertook just the first audit and those who retrofitted and also undertook the second audit. By comparing the pre-upgrade furnace efficiency and the EGH rating, we see that both variables have higher values (greater energy efficiency) for homeowners who did not proceed to the second audit, suggesting that those who undertook retrofit activities have a relatively greater need for (larger expected energy cost savings from) reducing energy consumption.

Thus, we observe that homeowners who did undertake retrofit investments were generally those with more severe energy efficiency problems. However, given that almost all of the homeowners audited the first time were given some upgrade recommendations - indicating that all had some energy saving potential through retrofitting, although to varying degrees -

Figure 2.5: Pre-Upgrade Energy Intensities

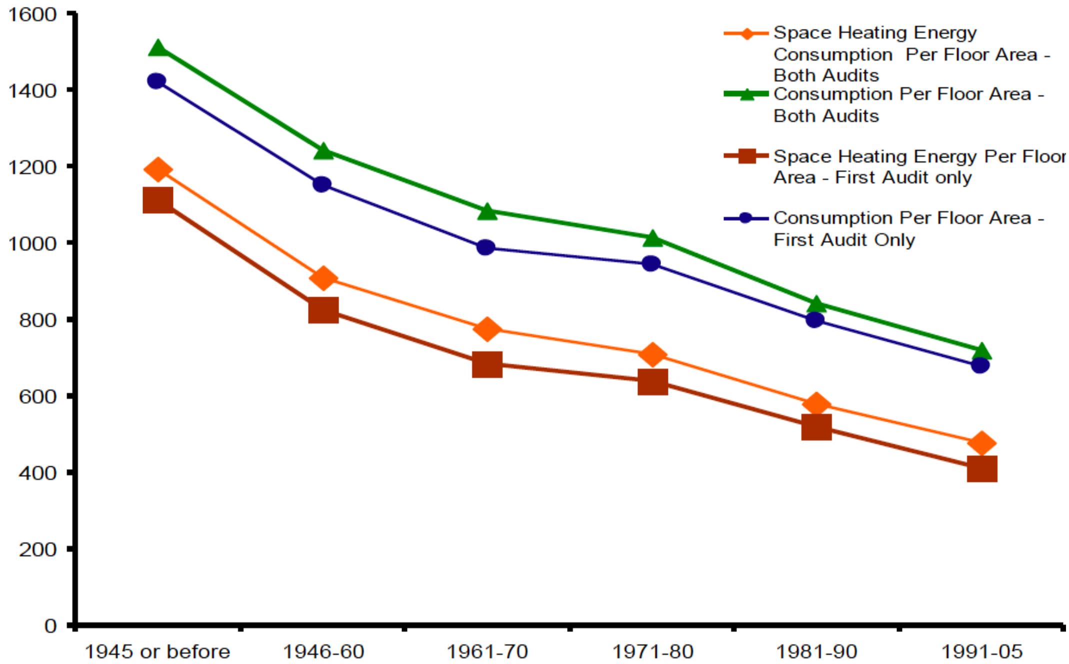


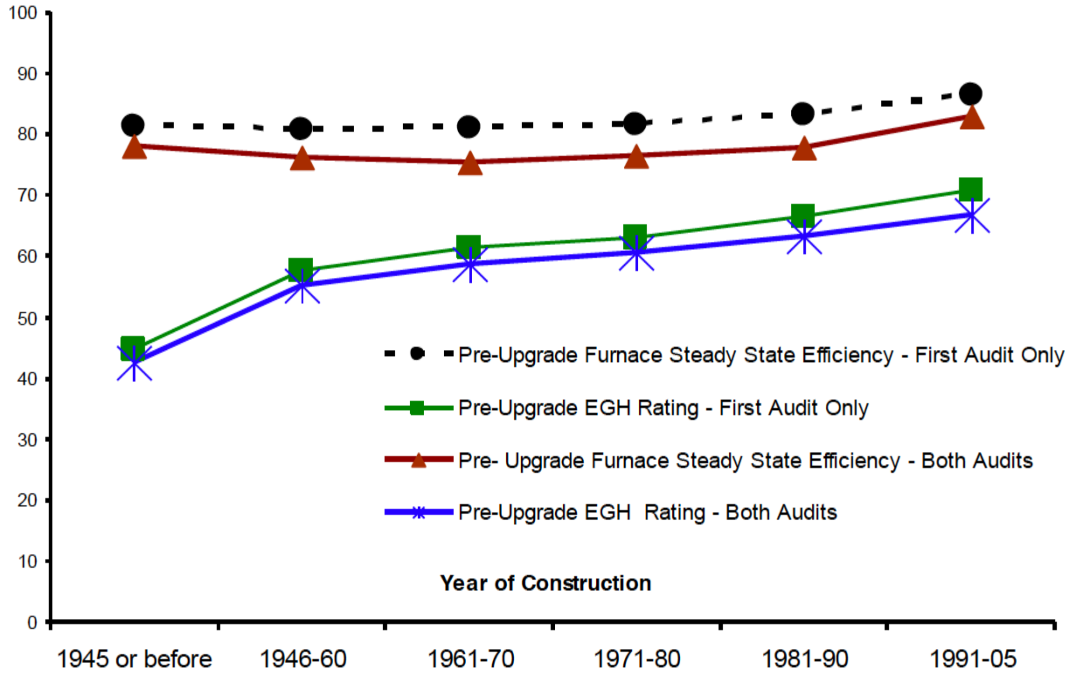
Table 2.8: Retrofit Probability by House Vintage and Upgrade Category (%)

	Thermal Envelope	Heating System Upgrade	DHW System	All
Before 1946	16.374	10.280	0.070	18.458
1946 - 1960	16.037	12.557	0.029	19.574
1961 - 1970	17.301	15.094	0.053	21.889
1971 - 1980	16.871	14.945	0.001	21.380
1981 - 1990	9.821	10.730	0.001	14.590
After 1990	4.691	3.496	0.001	6.718

it is interesting that only a small percentage of homeowners actually undertook sufficient retrofit investments to justify a second audit. The breakdown of retrofit probability by house vintage (Table 2.8) indicates that houses built before 1980 have relatively larger probability of retrofitting relative to houses build after 1980. This pattern applies to both thermal envelope and heating system upgrades. Improvements in domestic water heating systems were not common.

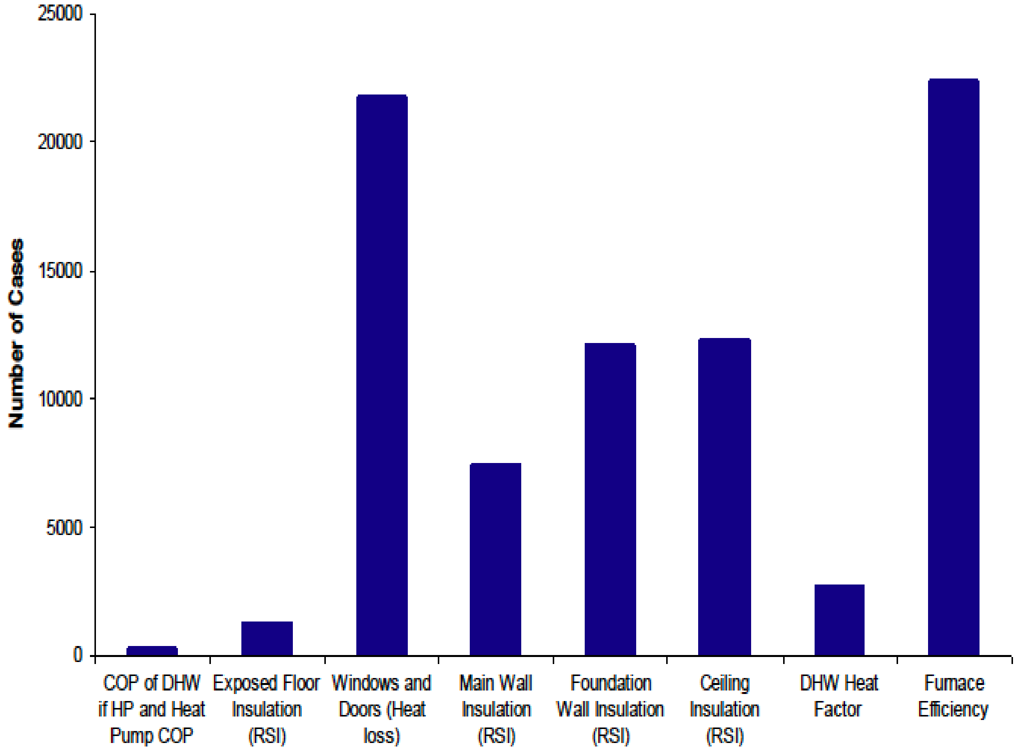
Of all the possible upgrades that could be made to the thermal structure, as shown in Figure 2.7, window and door upgrades were the most common, followed by foundation wall and ceiling insulation retrofits. This figure, along with the information in the preceding tables indicates that

Figure 2.6: Furnace Efficiency and EGH Ratings



there are considerable differences in the retrofit options chosen by different homeowners, and while in part this may have reflected the recommendations, of the auditors, it also likely reflects decisions made by homeowners based on budget constraints, what they considered to be more important, and the state of their house at the time of the first energy audit. As shown in Table 2.7, we observe that houses with greater energy saving potential are more likely to undertake retrofit upgrades, and that the higher is the energy-saving potential, the greater is the number of upgrades that are chosen. In particular, a poor EGH rating generally corresponds to a larger number of retrofit upgrades being undertaken, while larger ratios of pre-retrofit to post-retrofit energy consumption and cost (indicators of energy consumption and cost saving potential) are generally associated with homeowners undertaking more upgrades. Table 2.8 also supports this as it shows that older houses have larger retrofit probability. This feature - that houses with greater energy saving potential are more likely to undergo retrofit upgrades - was also apparent when we compared houses that underwent both audits with those who did not.

Figure 2.7: Number of Homes with Specific Upgrades

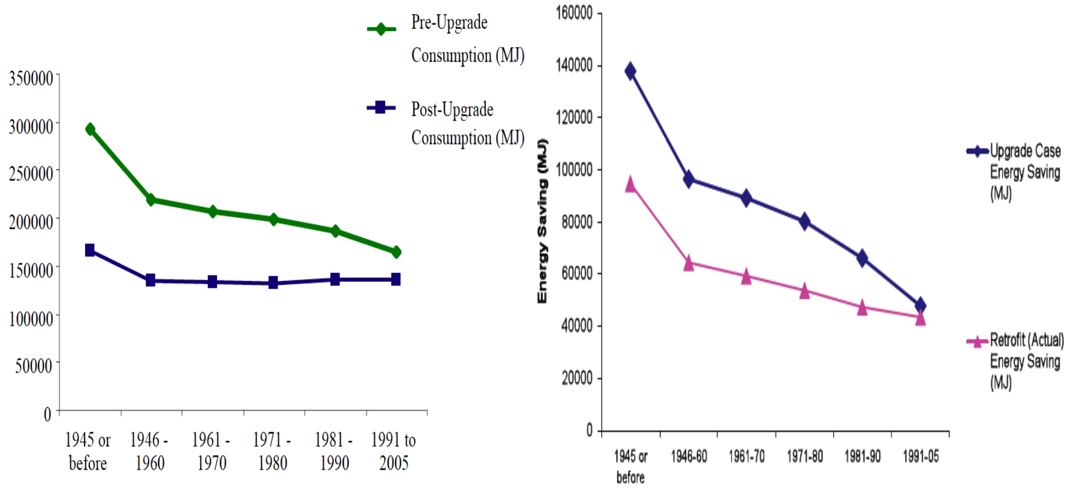


Effects of residential energy-efficiency retrofits

After undertaking retrofits, we observe that thermal efficiency of the homes has generally improved. Post retrofit data show that furnace efficiencies have improved, and fuel switching from propane and wood towards natural gas has occurred.

The effect on energy consumption is clear. As shown by Figure 2.8, engineering-based predictions of energy consumption declined for all house ages after retrofits. The major aim of retrofitting is to make older houses as close as possible to being as energy-efficient as newer ones. We observe this in the post-retrofit predicted energy consumption levels. The first panel in Figure 2.8 shows that the post-upgrade average energy consumption estimates per household per year is somewhat equal across all house ages between 1946 to 2005. Comparing this to the fact that pre-upgrade energy consumption of newer homes is relatively lower underlines the importance of retrofit on thermal efficiency. The second panel of Figure 2.8 compares estimated realized energy savings from retrofits to those expected from the upgrade recommendations. We observe that more energy savings are realized per house from the retrofitting of older houses as compared to

Figure 2.8: Effects of Retrofits on Energy Consumption



newer houses. In all cases, however, actual savings calculated in the second audit are less than the expected savings from the first audit.

This descriptive analysis, although important in highlighting important information, has limitations in terms of leading to conclusions regarding the relative importance of the underlying factors determining retrofit behaviour. We need to formally model retrofit behaviour estimates and test these models to obtain further insight into the matter at hand. The fact that energy consumption in the EGH data set is based on engineering-based estimates rather than actual consumptions does not, however, permit an econometric analysis of the effects of retrofits on energy consumption. The next section provides a review of the literature related to modeling and estimations in the context of our problem.

2.3 Literature Review

In this section, we discuss conceptual approaches and empirical facts available in the literature in order to facilitate our model specification. Our approach is based on a mixture of the frameworks discussed in this section.

Conceptual frameworks

There are three distinct conceptual approaches to modeling residential efficiency retrofit decisions or the purchase of energy efficient equipment. These are the random utility, cost-minimization, and maximization of net benefits approaches.

The random utility approach posits that a household chooses the retrofit alternative that generates the highest utility (Hausman, 1979; Dubin and McFadden, 1984; Train, 1985). The indirect utility from each alternative is assumed to be positively related to its efficiency characteristics, specifically the implied energy demand. Indirect utility is also assumed to be negatively related to the cost of acquisition (investment cost). Noting that the utilities are random from the researcher's point of view leads to the inclusion of a random component in the utility equation, which leads to the empirical specification of the probability that an alternative energy efficiency improvement scenario is chosen by the households. The utility equation is linear in both the capital and operating costs associated with each scenario. A problem that arises in such a framework is that only parameters corresponding to those factors that vary across the alternatives can be identified in estimating the probability that an alternative is chosen (Greene, 2003; Train, 2003). That is, household specific characteristics become irrelevant and in fact, many of the studies employing this framework do not consider household characteristics as important factors in the decision problem. This should not be considered as a major drawback to the conceptual framework, however, as one could consider the effect of individual specific attributes by including them in the estimation equation by cross multiplying them with the alternative specific constants so that they are allowed to vary across the alternatives (Greene, 2003).

A second approach views household retrofit investment decisions within the context of cost minimization. Jaffe and Stavins (1994) treat the decision problem as one in which homeowners attempt to minimize the costs of energy consumption. Given that such investments are often irreversible, the problem of optimal timing arises. Costs in Jaffe and Stavins consist of three elements: the present discounted value of annual energy costs from the present to time of adoption of the energy-saving technology, the present value of annual energy costs after the adoption, and the present value of the one-time cost of adoption of the energy-saving technology. These are dependent upon the energy-using characteristics of the technology in question, controlling for a vector of current and expected future values of observable characteristics of the home (such as size, type of heating equipment, etc), and region (for example, price of fuel, climate, average income and education).

Finally, Hasset and Metcalf (1993) view the decision problem as an attempt to maximize the net present value of the investment. By defining the net present value of investment in energy-efficiency retrofits as the discounted present value of the difference between energy cost savings resulting from the investment and the upfront capital cost, Hasset and Metcalf introduce uncertainty by assuming that the energy price path is random. Given that energy saving is affected by several variables, the approach can be generalized by letting the energy consumption path be related to underlying factors such as the thermal efficiency of the house, the equipment stock, and also to demographic characteristics.

Empirical Studies

Hausman (1979) provides a notable early empirical study analyzing residential energy conservation investment decisions in a model of the determinants of an individual's choice to acquire air conditioners with varying efficiency (low, medium and high efficiencies) and durability properties. According to the discrete choice approach (employed based on a random utility model), the item characterized with the high utility level has the highest probability of being adopted. Hausman shows that the probability of selecting a particular air conditioner is negatively related to both the operating and acquisition costs of the equipment. These costs are computed based on the capacity and efficiency properties and the average life of the appliances. More interestingly, the capacity of an air conditioner is modeled to depend on thermal conditions of walls, ceilings, floor areas, sizes of doors and windows and the amount of sun through the windows. Climate is also taken into account. The efficiency and durability properties were captured by dummy variables in the regression equation. The study shows that individuals generally tend to choose air conditioners that last longer and also are efficient at the time of purchase.

Using stated preference data from a sample of Canadian homeowners, Sadler (2003) estimates a model similar to the one developed by Hausman (1979). The choice equation is specified as a function of capital and operating costs, subsidies and the comfort levels associated with each upgrade scenario. Two separate models were estimated for renovation and heating system choices. In both cases, capital and operating costs enter the utility equations negatively while comfort and subsidies have positive effects in general. Banfi et al. (2008) provide evidence from experimental stated preference data from Switzerland and find that energy savings as well as comfort benefits determine retrofit choices.

On the other hand, Grosche and Vance (2009) estimate a choice model for various retrofit options using revealed preference data from a sample of German households. They find that the probability of choosing a retrofit option is positively related to the corresponding energy saving potential and negatively related to the costs. They also report that income has a negative effect on the probability of choosing energy efficiency retrofit options. In the same vein, Cameron and Wright (1988) analyze the determinants of shower head retrofits among households in California. They find that a household decision to install shower retrofit devices is influenced by the potential to save money on water heating bills. Cameron (1985) analyzes the determinants of retrofit choices in the US. The alternatives considered include undertaking no retrofits and each of a set of various possible retrofit combinations. Since there are several such possible combinations, a nested logit estimation method is used. The model is then used to simulate the effects of an increase in the relative price of fuel, a decrease in income, and a subsidy or tax credit. Results show that the retrofit decision is moderately elastic to changes in the relative price of fuel, i.e. an increase in cost of energy moderately encourages more retrofit activities. A decrease in real household income results in a decrease in retrofit demand. It is also shown that if the government were to offer to subsidize all retrofit expenditures by 15%, only about 0.2% of households would be induced to install at least one retrofit (Cameron, 1985).

Instead of modeling the choice to undertake retrofit upgrades, Long (1993) analyzes actual residential expenditure on energy conservation. In order to claim available tax credits as per the US Energy Conservation Tax Credit Act which allows home owners to reduce their federal income tax liability up to 15%, homeowners had to report the amount spent for energy conservation. By compiling information on these expenditure reports, Long analyzes the determinants of such expenditures for the period between 1978 and 1981. Expenditure on retrofit upgrades was found to be positively and significantly related to income. Similar relationships were found with energy prices, provincial/state subsidies, federal tax credits, and heating degree days. Household size is also shown to have positive effect on spending related to energy conservation.

Bonus (1973) provides additional evidence regarding the effect of income level on retrofit behaviour. Bonus uses the concept of vertical diffusion, a process by which individuals were converted from non-potential to potential adopters of a technology as their income increases, characterized by a shift in the intercept of the estimated quasi-Engle Curves for, among other items, refrigerators and televisions.[12] There is evidence for the so-called vertical diffusion process and hence income is an important variable in determining an individual's acquisition of energy saving technologies. It is shown that the fraction of ownership is higher for high income groups. The most important finding may be that not all individuals are potential adopters, as there is a certain critical income level that is required to acquire these technologies. Specific to energy conservation investment, Sutherland (1991) argues that low income individuals are inherently risk averse such that they generally refrain from undertaking risky investments unless granted a very high risk premium on the expected returns. Thus, they are less likely to undertake energy-efficiency investment as the associated returns are uncertain.

Building characteristics have also been shown to be important. For commercial and institutional buildings, Ryan et al. (2003) show that retrofit behaviour depends on such factors as building size, location, age of the building, type of ownership, and main heating source. Using the 2000 Canadian Commercial and Institutional Buildings Energy use Survey (CIBEUS) data, they find that government and non-profit private organizations tend to undertake more retrofit works as compared to profit-oriented private organization. This is of interest because it suggests that energy-saving upgrades may not be perceived to be profitable ventures.

In the context of residential energy retrofits in Canada, the statistical report on the 1994 residential retrofit survey published by Natural Resource Canada (1997) highlights a number of important relationships.

[12] A quasi-Engel curve is an equation that relates the odds of the probability to own an appliance to income.

In addition to outlining the patterns of upgrades undertaken by Canadian homeowners, this report shows that the main motivation for energy retrofits is energy savings. Hence, the age of the building played an important role in the decision to undertake energy-saving actions. There was a systematic increase in the frequency of activities to upgrade insulation, windows or doors in relation to the age of the home. The replacement or upgrading of heating equipment followed the same trend. Furthermore, the age of the household head and family income had significant effects. The higher the family income, the more the energy upgrades were undertaken. Furthermore, younger household heads tend to undertake more energy retrofits as compared to older ones. In a study analyzing the factors behind some Canadian homeowners' decision to keep their old fridges after purchase of the new energy efficient ones, Young (2008) finds that high income households that are owner-occupiers of single-detached homes are more likely to keep the old fridges. This might suggest that high income households may be less concerned about energy cost savings.

2.4 Modeling Residential Energy Retrofit Decision in the Context of the EGH Program

2.4.1 The retrofit investment decision problem

From the EGH data we see that all participating households were advised to undertake at least one upgrade, implying positive energy savings opportunities. However, less than 20% had received a second audit by October 2005. From a modeling perspective, we observe that, based on the first audit report, households are faced with a decision to invest in the one recommended alternative for a specific category. For example, households were recommended to upgrade their furnaces to a specific furnace type rather than being given an array of possible alternatives. Thus, their decisions do not involve making a choice from a menu of technologies; rather, they involve the case of undertaking an investment in terms of the specific upgrade recommended by the auditors. The main behavioural patterns we seek to model is, therefore, the probability of undertaking at least one category of upgrade (such as furnaces, windows, etc.) and the number of such upgrades undertaken - the propensity and intensity of retrofit investment by the households.

Energy efficiency choices fundamentally involve investment decisions that trade off higher initial capital costs and uncertain lower future energy operating costs (Gillingham et al., 2009). Consider the decision problem of a household head who has just completed the first audit and has a list of recommended upgrades. Each household was given Z number of upgrade types which would all together result in S_t amount of energy cost savings per year if implemented, according to the engineering estimates. The sets of upgrades involve an upfront cost of $\$K$ to the household. According to the engineering data, and the implied market cost of implementation, therefore, based on the net present value approach each upgrade set recommended to a household has a financial benefit of:

$$NPV = \sum_{t=0}^{n}(1+r)^{-t}S_t - K > 0 \tag{2.1}$$

where r is discount rate; and n is the life-span of the new capital purchased (retrofits done).[13]

Given the engineering calculation of $\$S_t$ and the market value of $\$K$, what other factors are important to the households in their actual upgrade decision? This question is the main topic of the research in this paper given that less than 20% of the participants had proceeded to a second audit.

In weighing the initial capital cost against the expected future savings, there are uncertainties about expected savings due to the fact that engineering estimates are valid only if the assumed scenarios, particularly the unit energy costs, prevail. Household specific characteristics are, however, important factors in investment decisions. To incorporate uncertainty and household characteristics, we specify the implementation criterion as:

$$E_0(NPV|\Theta) = E_0\sum_{t=0}^{n}(1+r)^{-t}[S_t|\Theta] - K > 0 \tag{2.2}$$

where E_0 is expectation operator based on information available at $t = 0$; and Θ is a vector of demographic, and other variables that are household specific. That is, there are uncertainties regarding the values of the implied NPV of the retrofits from the household's point of view, and household

[13] Note that this equation is based on the characteristics of the upgrade option. Hence, is not individual specific in the sense that the NPV is purely based on the engineering estimates of the energy saving potential as well as the market cost of the individual upgrade.

expectations are conditional on several other factors beyond the engineering estimates of energy cost savings.

For example, the variation in unit energy cost (energy price) can be an important source of uncertainty given that the estimates of energy costs depend on assumptions regarding future energy price trends. Moreover, it is important to control for several underlying factors regarding household characteristics.

Furthermore, the engineering estimates do not take into account any non-pecuniary benefits (that is, benefits unrelated to energy cost savings such as comfort) and such benefits are normally dependent upon subjective valuations of the decision makers which in turn depend on demographic characteristics, such as education and age. In short, we posit that even though households were informed about the engineering estimates of the implied energy cost savings for recommended upgrade scenarios, a household's valuation can differ from this. With the introduction of this individual heterogeneity into the model, two households with the same upgrade recommendations may not have similar propensities to implement the same recommended retrofits with identical projected energy savings as their subjective valuations differ.

The probability to undertake a specific retrofit investment is determined by the probability that $E_0(NPV|\Theta) > 0$. This is a simple "profitability" condition, that may not be a sufficient condition given the irreversibility of many retrofit options which suggests the possibility of the existence of option values from waiting.[14].

To specify our empirical model, consider that each household that was audited and obtained upgrade recommendations has a propensity to undertake the recommended upgrades Y^* conditional on several factors (X). We generally assume that the vector X is similar to the factors entering in the upgrade decision problem: S_t, r, K and Θ. In particular, we assume that:

$$Y_i^* = X'\beta + \epsilon_i. \tag{2.3}$$

[14]See Stoneman and Karshenas (1993) for modeling when the arbitrage condition (the no option value from waiting condition) is taken in to account in modeling investment/adoption decisions

where i indexes households, β is a vector of parameters capturing the effects of the $X's$ on the propensity to retrofit, and ϵ_i is the random component. The probability that a household undertakes at least one retrofit upgrade (given that at least one type of upgrade was recommended) is equal to the probability that the propensity to retrofit is positive, given by:

$$Prob(Y_i \geq 1|X) = Prob(X'\beta + \epsilon_i > 0|X). \tag{2.4}$$

where Y_i is the number of upgrades undertaken by household i. This can be rewritten following Maddala (1983) as:

$$Prob(Y_i \geq 1|X) = Prob(\epsilon_i < -X'\beta|X) = 1 - F(-X'\beta). \tag{2.5}$$

The function $F(-X'\beta)$ is the cumulative distribution function of ϵ_i. The effect of the j^{th} variable (X_j) on the decision to retrofit is given by:

$$\frac{\partial[1 - F(-X'\beta)]}{\partial X_j} = \beta_j f(-X'\beta). \tag{2.6}$$

where f denotes the density function. Marginal effects are, in general, a function of all explanatory variables and can be evaluated at the means of the variable values.

Modeling retrofit intensity - the number of various upgrades chosen- is important to shed a light on the underlying factors for the variations in retrofit intensities among those who have undertaken at least one upgrade. The focus here is the estimation of the probability that the number of upgrades takes a specific value:

$$Prob(Y_i = y_i|Y_i^* > 0) = Prob(Y_i = y_i|Y_i > 0). \tag{2.7}$$

where y_i is the number of upgrades undertaken by the households. Although it is expected that the same variables affecting the probability of retrofit also determine the intensity, it is also possible that some variables playing important roles in determining the general retrofit decision may not have important effects on the intensity. In general, the effect of a change in a particular variable can be decomposed into two components. First, its effect of inducing any retrofit upgrades (crossing from zero to one) and then the effect on the expected number of upgrades.

While we focus on modeling retrofit behaviour in terms of homeowners' decisions to implement the list of recommended upgrades during the first audit, retrofit behaviour could also be modeled in terms of homeowners' decisions to choose the various levels of energy cost savings that are associated with the particular retrofit choices. It is also possible to consider retrofit decisions in terms of the amount of investment costs that the homeowners chose to invest. These two options are, however, not possible to pursue in the context of our data given that the amount of energy costs savings are not specifically attributed to each type of upgrade. Also, investment costs were not provided in the data and we estimated using out sources. In some cases, it is not possible to estimate exact monetary costs of the upgrades. As a result, we use the retrofit counts to evaluate retrofit decisions, controlling for the total potential energy cost savings and the estimates of overall investment costs associated to the recommended upgrades. One disadvantage of using a count of retrofits is that individual retrofits are not necessarily comparable. One major retrofit, for example, may represent a larger improvement in a home's energy efficiency than two smaller retrofits.

2.4.2 Estimation Methods

2.4.2.1 The Binary Retrofit Decision

The most common assumptions for the distribution of ϵ_i are standard normal or logistic. Both imply that $F(-X'\beta)$ is equal to $F(X'(\beta)$ as these distributions are symmetric about zero. The *probit* model uses the normal distribution, that is $F(X'(\beta) = \Phi(X'\beta)$. The partial effect of the j^{th} continuous variable is given by:

$$\frac{\partial[1 - F(-X'(\beta)]}{\partial X_j} = \frac{\Phi[X'\beta]}{\partial X_j} = \beta_j \phi[X'\beta]. \tag{2.8}$$

where Φ is the cumulative density and ϕ is the probability density function of the standard normal distribution. The other distributional assumptions in modeling binary choices are the *Logit* which is based on logistic distribution and the complementary log-log, which takes the form:

$F(X'\beta) = 1 - exp\{-exp(X'\beta)\}$ (Cameron and Trivedi, 2005).[15]

Hypothesis and specification tests can be conducted using Wald or Likelihood Ratio tests. The Likelihood Ratio test is asymptotically equivalent to the Wald test if the the model is correctly specified. The predictive power of an estimated model can be evaluated in many ways including a comparison of the estimated probabilities to the actual outcomes where probability estimates below or equal to 0.5 are classified as zeros (do not retrofit) and estimates greater than 0.5 as ones (do retrofit). In this respect, it is possible for the model to have better predictive power for zeros relative to its predictive power for the positives, or vice versa. Hence, a preferred way to measure the goodness of fit of a model may be to compute a weighted sum of the separate probability predictions (Wooldridge, 2002).[16]

2.4.2.2 Retrofit Intensity

The variation in the number of upgrades undertaken by the homeowners ranges between 1 upgrade to 8 different upgrades undertaken. Explaining the factors underlying this variation is important. Thus, we use a zero-truncated count regression model to examine this variation.

The Poisson count-data econometric model is based on the Poisson distribution for the number of occurrences of the event y_i over a fixed period:

$$Prob(Y_i = y_i) = \frac{e^{-\mu_i}\mu_i^{y_i}}{y_i!}; E(Y_i) = \mu_i = var(Y_i). \tag{2.9}$$

with a mean parameterization assumption of $\mu_i = exp(X'\delta)$.

[15] In all three models, the partial effects depend on the values of the estimated coefficients, and the values of all variables in the model. It is a common practice to evaluate the marginal effects at the means of the variables in the model. The partial effects for dummy variables are calculated as the difference between the values of the estimated density functions evaluated at the two possible values of the dummy variable under consideration and the mean values of other variables.

[16] We present our estimation results for all the three distributional assumptions given that there are slight differences in the results. Based on the comparison of results, we adopt the best for our analysis of retrofit behavior. This step is mainly used for identification of which binary choice model to adopt in the overall model of retrofit behavior which seeks to explain retrofit intensity using a model based on a combination of binary choice and count data models (hurdle-count and zero inflated count data models).

Whether use of the Poisson model is reasonable can be guided by the result of *tests of over-dispersion,* as the assumption that $E(Y_i) = \mu_i = var(Y_i)$ has to be acceptable for the model's validity.[17] Tests of over-dispersion can be conducted by testing the null of equi-dispersion ($E(Y_i) = var(Y_i)$) against a form of over-dispersion: $Var(Y_i|X) = E(Y_i|X) + \alpha^2 E(Y_i|X)$. This amounts to testing whether $\alpha = 0$. One version of this test is to compute $z_i = \{(y_i - \hat{\mu}_i)^2 - y_i\}/\hat{\mu}_i$ from the Poisson regression, carry out an auxiliary regression of z_i on $\hat{\mu}_i$ with no intercept included, and then conduct a t-test of whether the coefficient on $\hat{\mu}_i$ is zero. Rejection of the null indicates the presence of over dispersion. As illustrated by Greene (2003), this test is valid for the specific form of over-dispersion considered here. Other tests, the conditional moment and the Lagrange multiplier (LM) tests, consider the same null hypothesis against a general form of over-dispersion in which variance is systematically related to the regressors in a way not completely accounted for by $E(Y_i)$. Testing Poisson against the negative binomial in general can be conducted using an LM test that is computed as $LM = n(\mathbf{e}'\mathbf{e} - \overline{y})/(2\lambda'\lambda)^{0.5}$ where n is number of observations, $\mathbf{e}'\mathbf{e}$ is sum of squared residuals from Poisson regression, $\overline{y}$ is average number of actual retrofits, and $\lambda'\lambda$ is squared sum of the predicted retrofit counts. Degrees of freedom for this test is the number of parameters including the constant term.

In the case of over-dispersion, the Poisson maximum likelihood estimator is still consistent under the assumption that $\mu_i = exp(X'\delta)$. Thus, the alternative methodologies attempt to accommodate over-dispersion while maintaining the mean-value assumption. One approach is to introduce *multiplicative randomness* to generate additional variability in y_i that can arise from unobserved heterogeneity. That is, μ_i is replaced by $\mu_i \nu$ where ν is a random variable. The most popular extension, the negative binomial (NB) model, is based on the assumption that $\nu \backsim \Gamma(1, \alpha)$ where α is the variance parameter of the gamma distribution. This assumption implies that the marginal distribution of y_i has a negative-binomial distribution - a Poisson-gamma mixture - denoted by $NB(\mu_i, \alpha)$ (See Cameron and Trivedi, 2005):

[17] A related problem is heteroskedasticity. This can, however, be handled by using a heteroskedastic robust variance-covariance matrix.

$$Prob(Y_i = y_i) = \frac{\Gamma(y_i + \frac{1}{\alpha})}{\Gamma(y_i + 1)\Gamma(\frac{1}{\alpha})} \left(\frac{\frac{1}{\alpha}}{\frac{1}{\alpha} + \mu_i}\right)^{\frac{1}{\alpha}} \left(\frac{\mu_i}{\mu_i + \frac{1}{\alpha}}\right)^{y_i}. \qquad (2.10)$$

with $E(Y_i|\mu_i, \alpha) = \mu_i$ and $var(Y_i|\mu_i, \alpha) = \mu_i(1 + \alpha\mu_i)$.

The NB model converges to Poisson as $\alpha \to 0$. While $E(Y_i|\mu_i, \alpha) = \mu_i$ is always the case, there are two variants in terms of the assumptions regrading the function governing the variance parameter - the NB2 which assumes quadratic variance function: $Var(y_i|\mu_i, \alpha) = \mu_i(1 + \alpha\mu_i)$; and the NB1 which assumes linear variance function: $Var(y_i|\mu_i, \alpha) = \mu_i(1 + \alpha)$.

Considering that over 80% of the observations have zero realizations, the count data models discussed above are not directly applied. There are two possible extensions to consider: i) the hurdle count-data model, and ii) the zero-inflated count-data model.

The hurdle model applies a binary choice model to the first stage problem (crossing the hurdle of zero), and a truncated-at-zero count data estimation techniques to the second stage. The basic idea in this method is that a binomial probability governs the dichotomous outcome of whether a count variable has zero or positive realization. If the realization is positive, the hurdle is crossed, and the conditional distribution of the positives is governed by the truncated-at-zero count data model (Mulahy, 1986; Cameron and Trivedi, 2005). The value of the log-likelihood for the overall model explaining retrofit behavior seen as a two-part decision is given by the sum of the respective values computed from the binomial model and the truncated-at-zero count data model.

To illustrate the approach, let $Prob(y = 0) = f_1(0)$, where $f_1(0)$ is the density function for zero realizations so that the probability of crossing the hurdle is given by $1 - f_1(0)$; that is, f_1 is a density of Probit or Logit distribution. The positive outcomes is governed by a truncated at zero density$f_2(y|y > 0) = f_2(y)/[1 - f_2(0)]$, where f_2 is a density of Poisson or NB distributions. Hence, the hurdle-count representation of the overall distribution is given by:

$$f(y) = \begin{cases} f_1(0) & if \quad y = 0, \\ \frac{1-f_1(0)}{1-f_2(0)} f_2(y) & if \quad y \geq 1 \end{cases}$$

The log-likelihood function of the hurdle-count model is the sum of the log-likelihood functions for the part governing the hurdle, and that of the count data model governing the truncated-at-zero counts. Calculation of the marginal effects of the overall model is not straightforward, however. Although there is a user-developed Stata command that can be used to estimate the overall model readily (Hilbe, 2005), the routine does not support computation of the overall marginal effects. Moreover, this user-written command requires the same set of regressors in each part. We, therefore, separately provide estimation results for retrofit probability (the probability of crossing the hurdle in this context) and the truncated-at-zero count data regression.

The zero-inflated count data model also supplements the count density $f_2(.)$ with a binary process with a density of $f_1(.)$ but the count density is not truncated in this case. The basic idea is that there are two sources of zeros: zeros may come from both the point probability mass at zero and from the count component. We have $y = 0$ if the binary process takes on a value of zero with probability of $f_1(0)$ whereas y takes on the count values 0, 1, 2, ... from the count density $f_2(.)$ if the binary process takes on a value of one with probability of $f_1(.)$. Hence, the zero counts occur both as a realization of the binary and count processes. The zero-inflated model has, thus, a density of:

$$f(y) = \begin{cases} f_1(0) + (1 - f_1(0))f_2(0) & if \quad y = 0, \\ (1 - f_1(0))f_2(y) \quad if & \quad y \geq 1 \end{cases}$$

Clearly, therefore, the probability of excess zeros is taken into account. Not only can the zero-inflated model describe zero-inflated count data more accurately than the standard count model, but it also provides more practical information regarding "none versus some" (the probability of positive counts) in addition to "how much given some" (the positive counts) (Winkelmann, 2008). There are proprietary Stata commands that can be used to estimate this model for Probit and Logit distribution assumptions for the binary part and Poisson and Negative Binomial distribution assumptions for the count part.

2.4.2.3 Some estimation issues

The EGH data are not drawn randomly from the population as they represent only those households who had their homes audited using the EGH auditors. Households decide whether to order a first EGH audit and also whether to undertake any recommended upgrades. Hence, there are elf selection problems. This leads to an issue of selection-bias in estimated results. Correction for this selection effect has, however, not been possible. Although the Survey of Household Energy Use conducted in 2003 (SHEU - 2003) provides information pertaining to homeowners intentions to undertake retrofits in a coming year, and hence selection equations could be estimated from this randomly drawn data, it would not be possible to match the inverse Mill's ratios with observations in the EGH data. Computing average values for each province is not of help given that these would overlap with province dummies.

Even though we are not able to take selection factor into account, the fact that both self-selection (the probability of ordering first audit) and the decision to undertake some renovations are driven most likely by the same underlying factors (energy efficiency problems) may mean that our results may not be severely biased. For example, in the context of the SHEU - 2003 data, of the Canadian homeowners and landlords / property managers who did not make any improvements in 2003 and were not planning on making any improvements in 2004, the majority (64%) stated that improvements were not necessary while another 17 percent said that improvements were too costly (Natural Resource Canada, 2006). If they were to undertake some upgrades, they might order EGH audits given the associated financial incentive which would mean that they would self-select into the EGH program based on the same underlying factors that drive the second audit (retrofit investments). This can be viewed in the econometric framework of sequential decision models in which the decision functions in all stages are identical (Maddala, 1983), which suggests that ignoring one of the decision functions may not reduce any bias.

Another important point to note is the problem of free-ridership. While the main purpose of the EGH audit is information provision, particularly before the introduction of financial rebates, it is possible that there are certain well-informed homeowners who might have used EGH audits, especially given that the audit itself was subsidized in some provinces, in order to receive rebates and therefore reduce the costs of retrofits that they had already decided upon. Another motivation of such agents may be to obtain the expert report in order to increase the market values of their homes. This may partly explain some of the zero outcomes in the second audits. It should, however, be noted that such homes are most likely to be highly efficient and that by itself explains why they were not renovated. Our econometric model seeks to explain participation in the second audit, not the first one. Thus, free-ridership may result in too much participation in the first audit, or participation with no intention, from the outset, to proceed to the second audit, but such strategic behavior itself is a function of energy efficiency characteristics.[18]

2.4.3 Explanatory variables

We model retrofits as a function of household characteristics and the attributes of the upgrade scenario prescribed to each home audited, controlling for a number of other factors. Households characteristics considered include the number of household members, age composition, education, and income. Even though the EGH data set does not contain the measures of these socioeconomic and demographic variables, it is possible to at least include average measures for factors. Information provided in the EGH data set allows identification of the location of the house up to the level of the Forward Sortation Area (FSA), that is, the first three digits of the home owner's postal code. Using this information, it is possible to match houses in the EGH data set with demographic information obtained from other sources. Specifically, information from the 2001 Canadian census pertaining to such variables as income, education, household size, number of children, and age composition of households in the participant's FSA can be included in this manner.[19] Typically, these variables are in the form of the percentage of the population in a certain income range or with a certain educational qualification. Unfortunately, these variables are only available for the one "census year" that falls within the EGH program period. Annual

[18]" While homeowners are implementing energy efficiency retrofits that may have been done even without the financial incentives, homeowners are undertaking double the number of retrofits they had originally planned and 60% of them are motivated to undertake further measures outside of the program. This suggests that retrofit programming is expanding or modifying the energy retrofit activities of the homeowners" NRCan (2010); `http://www.nrcan.gc.ca/evaluation/reprap/2010/e20100915-eng.php`

[19]I am indebted to Professor David Ryan for providing these data.

tax-filer data are available by FSA on a more frequent annual basis. This information pertains mainly to various income measures. The inclusion of census data in this fashion implied that there is no matching information for some observations, prompting us to exclude them from our analysis. The attributes of the upgrade scenarios obtained from the EGH database are the engineering estimates of related energy cost savings, the implied improvement in the EGH rating since it is the main determinant of the size of the grant the homeowner would receive, and the implied investment costs.

In addition to these household and the upgrade specific attributes, we posit that the retrofit decision is affected by the existing energy efficiency characteristics of the houses as indicated by thermal envelope qualities as well as the efficiency characteristics and fuel types of the furnaces, domestic water heaters, and heat pump efficiencies. We represent thermal insulation qualities by ceiling, main wall, and foundation wall insulation, windows and doors energy efficiency characteristics represented by respected heat loss as a ratio of total heating energy; exposed floor insulation; a measure of air tightness of the houses; house age; floor area; number of rooms; plan shapes; number of floors and house type. We assume that better efficiency characteristics imply a lower probability of undertaking energy efficiency retrofits.

Capital costs associated with a particular upgrade are estimated using a unit capital cost formula for that specific upgrade type for the province in which the house is located. This methodology was developed by Guler et al. (1999) and also applied by Aydinalp et al. (2001). The equations, and the relevant information used in the calculations are provided in Appendix A. These calculations are conducted by considering the cost estimates of the respective recommended upgrade types from the initial audit. The costs of heating system upgrades can be matched by the recommended efficiency and fuel type of the heating system equipment (furnace, boiler, domestic water heater, and heat pump) to the cost schedule given in Appendix A, Tables A.1. For the thermal envelopes (ceiling, main wall, and basement wall) insulation, window and door upgrades, and air sealing, however, we do not have sufficient information to be able to compute the exact monetary amount associated to the upgrade recommendations. In order to proxy the household specific variations (depending on the characteristics of their specific upgrades) in the unit costs, we consider that the area that requires insulation is directly proportional to the amount of the needed reduction in heat losses. To this effect, we scaled the unit costs of the thermal envelope insulation by both the recommended change in the respective RSIs[20] and the corresponding initial heat loss as a ratio of total heating energy consumption. We applied the regional adjustment factors given in Appendix A, Table A.2 to these calculations. The estimated costs for thermal envelope renovations are, thus, simply an indicator. For heating system upgrades, however, they are actual estimates of monetary costs.

The date of first audit, the expected change in EGH ratings, estimated retrofit costs; and upgrade case energy cost savings, are included to capture the incentives and costs of retrofits. Because the expected grant amount is directly related to the improvements in EGH ratings, we posit that a higher upgrade case change in this rating leads to a higher probability of undertaking retrofits. The more recent the first audits are the less likely that recommended upgrades have been completed. We capture this by using a dummy variable that takes a value equal to one for all first audit dates after August 2003. As per the decomposition in Table 2.10, we also include a dummy for observations that have undergone first audit less than 18 months before the cut-off date, October 2005. On the other hand, because financial incentives were introduced more recently, the houses that were audited recently would more likely undertake more upgrades because the financial incentives would offset part of their costs. Hence, we expect a negative effect on the probability of retrofitting while we expect a positive effect on retrofit intensity.

Summary statistics for selected variables are provided in Table 2.9. The summaries are calculated after cleaning the data to prepare for estimation by first deleting any observations with obvious errors in data recording. For instance, there were observations wherein the upgrade case EGH ratings were less than the initial EGH ratings; there were observations with zero upgrade case energy cost even though the respective energy consumptions were not; and there was one observation with a negative upgrade case heat loss through the ceiling. We drop observations from the three Canadian Territories (Nunavut, Yukon, and Northwest) because there were no observations with a second audit from Nunavut and participation in the first audit itself was low. For estimation, we drop cases with missing data or with values that are not plausible. As a result, the total number of

[20] Also known as an R -Value, this is a measure of thermal resistance of a building.

observations in the first audit is reduced to 183,392 while the number with a second audit is 34,944 (19% of total).

The dependent variable, the number of actual upgrades for all homes that have undergone a first audit, ranges from zero (for those who did not do any retrofitting) to 8, with a mean value of 0.5. The average number of upgrades for those who have undergone a second audit is about 2.6. The average year of construction is 1960, with an average floor area of 221 m^2; the average numbers of rooms and floors are 6.5 and 1.6, respectively. The efficiency characteristics of the homes - ceiling insulation, foundation and main wall insulation RSIs are also given. The expected average change in EGH rating is 14.6, and is as high as 82 for some observations.

The average number of occupants is 3.4, with a maximum household size of 9. The average household income is $63,229 and ranges from $23,364 to $279,759. Only a small percentages of household members, about 8%, have no high school education. About 60% of the household members are within the age group 20 to 64.

The average value of engineering estimates of energy cost savings is $867.63, ranging between $0.01 to $17,844. We look at this number cautiously as it appears difficult to justify such a large energy cost saving. Our analysis of the data reveals that the 99^{th} percentile is only $3,841.53 and only 1,834 observations are characterized by expected energy cost savings above this figure. We exclude these observations from the estimation analysis. The estimated heating equipment upgrade cost ranges between $0 (for observations with no recommendation to upgrade heating equipment efficiency) to $5,634. The cost indicator for thermal envelope insulation costs ranges between 3.3 to 92.[21]

After dropping observations with unreliable energy cost saving data, we decomposed the observations according to the audit dates (Table 2.10). Of the 181,558 remaining observations, 33.5% were audited before the introduction of government rebate incentives. By the cut-off date of the data, for over 52.75% of the observations the “clock” (the 18 months period) allowed to undergo second audit and apply for rebates had run out, while 47.25% still had some time left. The observations that had some time left by the cut-off date of the data account for over 51% of the observations

[21]See appendix for information regarding what these values represent

Table 2.9: Summary Statistics for Selected variables

Variable Name [a]	Mean	St. Deviation	Minimum	Maximum
Number of actual upgrades [b]	0.50	1.17	0.00	8.00
House Characteristics from EGH data [c]				
Year built	1960.20	27.49	1690.00	2005.00
Number of room	6.53	0.79	3.00	10.00
Floor area [d]	221.01	87.06	30.4	2982.00
Ceiling Insulation RSI	4.013	1.84	0.00	23.07
Foundation Wall Insulation RSI	1.46	5.07	0.00	391.00
Main Wall Insulation RSI	1.82	0.615	0.00	10.57
Number of Storeys	1.56	0.57	1.00	3.00
Heating System Characteristics				
Furnace Efficiency [e]	81.00	10.48	20.00	100.00
DHW heating system efficiency [e]	61.06	13.37	1.90	100.00
Household Characteristics from Census data [f]				
Number of occupants	3.43	1.11	1.00	9.00
Proportion of household members with no high school education	0.08	0.05	0.00	0.39
Proportion of household members with high school education	0.30	0.07	0.00	0.04
Proportion of household members with trade certificate and college education	0.35	0.05	0.11	0.54
Proportion household members within age group of 20 to 64	0.61	0.04	0.32	0.86
Proportion within age group above 64	0.13	0.05	0.004	0.62
Average household income	63228.97	20074.44	23364	279759
Others				
Year and Month of first audit	2003.82	1.68	1998.83	2005.75
Upgrade change in EGH rating	14.60	10.88	0.00	82.00
Upgrade energy cost saving	867.63	775.06	0.01	17844.39
Heating Equipment Upgrade Costs	3462.99	754.72	0.00	5633.71
Thermal Insulation Upgrade Cost Indicator	13.57	3.57	3.29	92.09

[a] Dummy variables (regional, furnace fuel types; house type; and house shape dummies) are excluded. Number of observations is 183392.

[b] Mean value for the positive counts is 2.623397.

[c] Number of rooms is from census data

[d] Estimated in EGH data using House Volume (M^3)/2.5 Foot print (M^2).

[e] We excluded observations with zero values. The number of observations used for furnace efficiency is 183388; and 182896 for DHW efficiency.

[f] Number of occupants is from EGH data.

Table 2.10: Decomposition by Audit Date

	Number	%
Total Observations with first Audit	181,558	
		% of Total
Number first audited before October 2003	60,764	33.50
Number first audited at least 18 Months before cut-off date	95,777	52.75
Number first audited less than 18 Months before cut-off date	85,781	47.25
Total Observations with second audit	34,584	19.05
		% of second audit
Number with first Audit before October 2003	10,576	30.60
Number with first Audit at least 18 Months before cut-off date	23,944	69.23
Number with first Audit during the last 18 Months before cut-off data	10,640	30.77
		% of Total
Total Observations with no second audit	146,974	81.00
		% of no second audits
Number first audited less than 18 Months before cut-off date	75,141	51.12

with no second audit. To account for these, we use two dummy variables in our estimations; one to account for whether the homes were audited before the introduction of rebates and second to account for whether the homes had not run out of the clock by the cut-off date. We predict that both these variables will have negative effects on the probability that the homes had undergone retrofits.

2.5 Estimation Results

We estimate the retrofit probability model using the three underlying distributional assumptions: probit, logit, and complementary log-log (cloglog). The results are generally consistent across the first two specifications (Table 2.11). The estimated marginal effects are very close in magnitude, and have the same signs. The estimates obtained from the cloglog specification are a bit different. We have two cases in which the statistical significance of the estimated coefficients were different from the predictions from the first two, and the magnitude of the marginal effects are also different in most cases. Model comparison using the Akaike information criterion suggests that the logit specification performs slightly better. The overall fit in all cases is quite good based on (i) the Wald test of overall significance; (ii) in the cases of probit and logit specifications, the percentage correctly classified by the model (81%), and iii) the estimated probability of retrofits. It appears that probit specification performs better in terms of the estimated probability of retrofits (0.164 against the actual of 0.19).

We present estimation results for the retrofit counts in Table 2.12. We provide truncated-at-zero Poisson and Negative Binomial as well as the zero-inflated Poisson regression results.[22] The truncated count regression results provide information regarding retrofit intensity choice among the homes that were retrofitted. According to the hurdle model, the overall retrofit decision is explained by looking at both the probability and the counts of retrofits. We could not compute the total effects from this estimation because integrating the two separate estimates is not straight forward.[23] Our insights regarding the overall effect of a variable on retrofit decision is, therefore, based on the marginal effects computed from zero-inflated Poisson regression, which captures the total effects of a variable on both the probability and intensity of retrofits by construction. We observe that some variables that play important roles in determining retrofit probability are not significantly affecting the retrofit intensity as shown from the truncated-at-zero Poisson and Negative Binomial regression results presented in Table 2.12. What is clear from these estimates is that most of the variables have additional effects that we have to take into consideration in determining their effects on overall retrofit decisions (both the probability to retrofit and the number of retrofits to be chosen). Furthermore, there are variables that have opposite effects on retrofit probability and retrofit counts. To this effect, a consistent story about the effect of a variable on retrofit decisions can be told only by looking at the total effect.

We note from the estimation results that the date of first audit has an important effect on the likelihood that the homes had undergone a second

[22] We do not include zero-inflated negative binomial results because convergence could not be reached in the estimation process and it is not essential given that we rejected the null for over-dispersion. Following the truncated Poisson regression, we computed the LM test of over dispersion and obtained LM = 9.45 with 36 degrees of freedom. This shows that we can not reject the null hypothesis at conventional levels of significance. The almost identical estimates we obtained from both truncated Poisson and negative binomial confirms this conclusion.

[23] This is very difficult to program because any such approach has to take into account the simultaneous changes in both the coefficients and the probabilities as a value of a variable changes.

audit by the end of 2005. We used two dummy variables to account for the date of first audit. First, we accounted for whether the first audit was before or after the introduction of government incentives in 2003. Second, we accounted for whether the first audit date was less than 18 months before the cut-off date for the data. The dummy variable for first audit dates less than 18 months before the cut-off date merely captures whether or not the clock had run out by the cut-off date, and simply accounts for the possibility that these homes may still be retrofitted. We found negative coefficients on this variable in all cases, signifying the importance of taking it into account. We find that the homes that were audited before the introduction of government incentives were less likely to undergo retrofits, controlling for other factors (Table 2.11). We observe similar effects on retrofit intensity (Table 2.12, columns 1 & 2). As a result, the overall effect on the retrofit decision is negative (Table 2.12, columns 3 & 4). This reveals the importance of government incentives in the EGH program on retrofit decisions.

Breaking down the years of construction by decades, we observe that the houses built before 1991 are more likely to be retrofitted than others. In terms of retrofit counts, however, statistically significant differences were instead observed between houses built before 1981 relative to the houses built after 1980. Year of construction of a house has, therefore, an important effect on retrofit decisions. This is mainly related to changes in the building standards in 1980 (Sadler, 2003). We find that houses with larger floor area are less likely to be retrofitted. However, among the ones that are retrofitted, the larger the floor area, the more is the number of retrofits. We found that attached/row and mobile homes, as well as multi-floor homes are less likely to be retrofitted. Homes that are privately owned are more likely to be retrofitted and undergo more of the various retrofit options, indicating that it is an important factor in retrofit decisions. It appears that house shapes, and layouts also play a role. Homes with fewer than 6 corners appear to be more likely to be retrofitted as compared to others. Location is also found to be important. Relative to Quebec, homes in all provinces, except Prince Edward Island and Newfoundland are more likely to get retrofits. The effect of location dummies on retrofit counts among the homes that get retrofits is however not as clear-cut. We actually observe negative relative marginal effects on retrofit counts for most provinces. The signs of the overall marginal effects on retrofit decisions are, however, the same as the predictions for retrofit probability.

The thermal efficiencies of the homes, measured by main and basement wall insulation, are also important determinants of retrofits. We found that more efficient homes are characterized by both a lower probability and number of retrofits. Along the same tune, efficiencies of the heating systems - furnace efficiency and domestic water heating system efficiency- are also important factors.

We find that household size, household income, age composition of the household members, and education levels have effects on retrofit decisions. Larger household sizes imply a lower likelihood of retrofit investment. High income households are less likely to undertake retrofit investment, possibly because energy expenditure accounts for a very small share of their income such that they may not care much. Perhaps, due to a similar reason, we observe that homeowners with no high school education, and therefore more likely to earn less income, are the ones more likely to retrofit their homes relative to those with high school and higher education. We observe that households with larger proportions of people with ages above 19 are more likely to retrofit. Of all the household characteristics, only household income and the proportion of household members with ages above 64 affect retrofit intensity.

Controlling for all these factors, we can assess whether or not there is any role for financial incentives in driving retrofit investment. First, one of the incentives for the households is their expected energy cost savings measured by the upgrade case (estimated during the first audit) energy cost savings. We find that this variable positively and significantly contributes to retrofit probability. A second incentive is the expected rebate from the government. The expected government rebate is indicated by the difference between upgrade case and initially assigned EGH ratings. Larger differences imply larger retrofit rebates. We find a statistically significant positive effect associated to this variable. This suggests that from among the homeowners who decide to undertake retrofits, the ones that expect more financial rebates are more likely to spend more on retrofits. Together, the two variables indicate that the larger is the expected financial gain from the investment, the more likely are households to undertake retrofit investment and invest in many upgrade types.

As discussed earlier, we include costs of heating equipment upgrades and thermal insulation separately because of differences in how they are

Table 2.11: Estimated Marginal Effects for the Probability of Retrofits

	Probit	Logit	Cloglog
House Characteristics			
Number of Rooms	0.0227***	0.024***	0.0234***
Floor Area	-0.0001***	-0.0001***	-0.0001***
Storeys	-0.0058***	-0.0053***	-0.005***
Foundation Wall Ins.	-0.0031***	-0.0035***	-0.00353***
Main Wall Insulation	-0.013***	-0.0129***	-0.0124***
House Type - Semi Detached	-0.021***	-0.019***	-0.0171***
House Type - Row House	-0.025***	-0.0234***	-0.0226***
House Shape - 11 or more corners	-0.011***	-0.0111**	-0.0098**
House Shape - 5 to 6 corners	0.029***	0.028***	0.025***
House Shape - Rectangular	0.012**	0.0114***	0.0109***
Percent of dweller-owned houses	0.03364**	0.025***	0.016*
Year of Construction before 1946	0.052***	0.061***	0.0667***
Year of Construction- 1946 to 1960	0.074***	0.0831***	0.0875***
Year of Construction- 1961 to 1970	0.111***	0.1224***	0.125***
Year of Construction- 1971 to 1980	0.1115***	0.126***	0.129***
Year of Construction- 1981 to 1990	0.0684***	0.07778***	0.084***
Heating System Characteristics			
Furnace Efficiency	-0.004***	-0.0038***	-0.0032***
Fuel Type - Oil	-0.0394***	-0.0339***	-0.028***
Fuel Type - Wood	-0.117***	-0.1116***	-0.1058***
Household Characteristics			
Average household Income	-0.0000007***	-0.0000007***	-0.0000007***
Number of Occupants	-0.0095***	-0.009***	-0.007***
Proportion of household members with no high school eductation	0.099***	0.086***	0.0673
Proportion of household members with age between 20 to 64	0.415***	0.391***	0.353***
Proportion of household members with age above 64	0.43***	0.41***	0.37***
Basement thermostat set point	-0.0114***	-0.0123***	-0.0127***

Note: *** Indicates significance at 1% and ** indicates significance at 5% level of significance; while * indicates that it is statistically insignificant
Percent owned refers to percent o

Table 2.11 Continued: Estimated Marginal Effects for the Probability of Retrofits

	Probit	Logit	Cloglog
Province			
Province - Alberta	0.063***	0.069***	0.073***
Province - British Columbia	0.088***	0.097***	0.105***
Province - Manitoba	0.0953***	0.108***	0.1152***
Province - New Brunswick	0.135***	0.147***	0.152***
Province - Nova Scotia	0.0544***	0.0652***	0.071***
Province - Ontario	0.0965***	0.106***	0.112***
Province - Saskatchewan	0.1052***	0.113***	0.115***
Province - New Foundland	-0.0787***	-0.0781***	-0.076***
Others			
Dummy for first audit before October 2003	-0.135***	-0.123***	-0.111***
Dummy for first audit less than 18 Months before cut-off date	-0.187***	-0.176***	-0.164***
Number of Recommended Upgrade Cases	-0.0002*	0.0035*	0.0061***
Thermal envelope Upgrade Cost Indicator	-0.00278***	-0.00303***	-0.00251***
Thermal envelope Upgrade Cost Indicator Squared	0.00001***	0.00001***	0.00001***
Heating System/Equpment Upgrade Cost	0.00001***	0.00001***	0.00001***
Heating System/Equpment Upgrade Cost Squared	-0.0000000002***	-0.0000000002***	-0.0000000001***
Upgrade Case (Potential) Energy Cost Saving	0.00002***	0.00002***	0.00002***
Upgrade case increase in EGH Rating	0.001***	0.001***	0.0002*
Number of Observations	181558 (Zero outcomes =146974, Nonzero outcomes = 34584)	181558 (Zero outcomes =146974, Nonzero outcomes = 34584)	181558 (Zero outcomes =146974, Nonzero outcomes = 34584)
Log likelihood	-78648	-78642	-78700
LR $Chi^2(41)$	19515	19526	19411
Prob> Chi^2	0.0000	0.0000	0.0000
Pseudo R^2	0.1104	0.1104	N/A
AIC	157380	157369	157483
Estimated Probability of positives	0.1640	0.159	0.156
Percent correctly classified	81.44'%	81.47'%	N/A

Note: *** Indicates significance at 1% and ** indicates significance at 5% level of significance; while * indicates that it is statistically insignificant

Table 2.12: Estimated Marginal Effects on Retrofit Intensity

	Zero Truncated Poisson	Zero Truncated Negbin	Zero Inflated Poisson (Probit Inflation)	Zero Inflated Poisson (Logit Inflation)
House Characteristics				
Number of Rooms			0.056***	0.059***
Floor Area	0.0004***	0.0004***	-0.0003***	-0.0002***
Storeys	-0.111***	-0.111***	-0.028***	-0.027***
Foundation Wall Ins.	-0.014***	-0.014***	-0.010***	-0.0104***
Main Wall Insulation	0.091***	0.091***	-0.023***	-0.024***
House Type - Semi Detached	-0.127**	-0.127**	-0.068***	-0.063***
House Type - Row House	-0.123***	-0.123***	-0.077***	-0.073***
House Shape - 11 or more corners	-0.092**	-0.092**	-0.039***	-0.039***
House Shape - 5 to 6 corners	-0.071***	-0.071***	0.062***	0.060***
House Shape - Rectangular			0.029***	0.028***
Percent Owned	0.177***	0.177***	0.114***	0.092***
Year of Construction before 1946	0.387***	0.387***	0.198***	0.214***
Year of Construction- 1946 to 1960	0.256***	0.256***	0.235***	0.252***
Year of Construction- 1961 to 1970	0.206***	0.206***	0.327***	0.350***
Year of Construction- 1971 to 1980	0.204***	0.204***	0.32***	0.37***
Year of Construction- 1981 to 1990			0.176***	0.196***
Heating System Characteristics				
Furnace Efficiency	-0.004***	-0.004***	-0.011***	-0.010***
Fuel Type - Oil	0.168***	0.168***	-0.081***	-0.070***
Fuel Type - Wood	0.849***	0.849***	-0.26***	-0.25***
Household Characteristics				
Average household Income	-0.000002***	-0.000002***	-0.000002***	-0.000002***
Number of Occupants			-0.025***	-0.023***
Proportion of household members with no high school eductation			0.266***	0.236***
Proportion of household members with age between 20 to 64			1.05***	1.002***
Proportion of household members with age above 64	0.826***	0.826***	1.19***	1.14***
Basement thermostat set point			-0.03***	-0.03***

Note: *** Indicates significance at 1% and ** indicates significance at 5% level of significance; while * indicates that it is statistically insignificant

Table 2.12 Continued: Estimated Marginal Effects on Retrofit Intensity

	Zero Truncated Poisson	Zero Truncated Negbin	Zero Inflated Poisson (Probit Inflation)	Zero Inflated Poisson (Logit Inflation)
Province				
Province - Alberta	-0.076*	-0.076*	0.137***	0.155***
Province - British Columbia	-0.358***	-0.358***	0.151***	0.175***
Province - Manitoba	-0.137***	-0.137***	0.203***	0.234***
Province - New Brunswick	0.319***	0.32***	0.42***	0.454***
Province - Nova Scotia	0.054*	0.054*	0.15***	0.17***
Province - Ontario	-0.165***	-0.165***	0.21***	0.24***
Province - Saskatchewan	-0.333***	-0.333***	0.18***	0.21***
Province - New Foundland	-0.48***	-0.48***	-0.234***	-0.232***
Others				
Dummy for first audit before October 2003	-0.04**	-0.04**	-0.35***	-0.32***
Dummy for first audit less than 18 Months l	-0.152***	-0.152***	-0.491***	-0.468***
Number of Recommended Upgrade Cases	-0.007*	-0.003*	0.010*	0.003*
Thermal envelope Upgrade Cost Indicator	0.038***	0.038***	-0.005***	-0.005***
Thermal envelope Upgrade Cost Indicator	-0.00024***	-0.00024***	0.000024***	0.000025***
Heating System/Equpment Upgrade Cost	0.00002***	0.00002***	0.00003***	0.00003***
Heating System/Equpment Upgrade Cost Squared	-0.0000000002	-0.0000000002	-0.0000000005***	-0.0000000005***
Upgrade Case (Potential) Energy Cost Saving	0.0001***	0.0001***	0.0001***	0.0001***
Upgrade case increase in EGH Rating	0.013***	0.013***	0.003***	0.003***
Number of Observations	34584	34584	181558 (Zero outcomes =146974, Nonzero outcomes = 34584)	181554 (Zero outcomes =146974, Nonzero outcomes = 34584)
Log likelihood	-52909	-52909	-131566.8	-131554.8
LR $Chi^2(34)$	5453	4762	4724	4720
Prob> Chi^2	0.00	0.00	0.00	0.00
Pseudo R^2	0.05	0.04	N/A	N/A
Estimated Average Number Events	2.26	2.26	0.41	0.40
Actual Average Number of Events	2.61	2.61	0.50	0.50
Vuong test of Zero Inflated vs. Standard Poisson under Ho: Standard Poisson is correct specification((Z) =			157.19 (Pr >Z = 0.00)	157.33 (Pr >Z = 0.00)

Note: *** Indicates significance at 1% and ** indicates significance at 5% level of significance; while * indicates that it is statistically insignificant

measured. These costs are found to have statistically significant negative effects on retrofit probability. They also affect retrofit counts negatively.[24]

2.6 Summary and Conclusion

We provide a description of the EGH data with a focus on major trends such as regional distribution of participants, furnace and domestic water heating systems, house characteristics, and recommended upgrades. The descriptive statistics suggest that homeowners who proceeded to a second audit after undertaking energy-efficiency upgrades were characterized by relatively poor initial energy efficiency conditions. As expected, given the nature of upgrades, average household energy requirements declined after retrofits. Moreover, the amount of engineering-calculated energy savings appears to be directly proportional to retrofit intensity. There is also induced fuel-switching taking place particularly from propane and oil to natural gas.

We conduct an econometric analysis to investigate retrofit behaviour in a multivariate context and to estimate the specific roles of various factors related to energy efficiency and economic characteristics in determining the probability and intensity of retrofit investments. Our analysis reveals that while households with more initial energy inefficiency problems due to less efficient thermal envelopes and heating systems are the ones more likely to undertake retrofit investments, in general, financial incentives appear to play very important roles. The larger the expected energy costs savings and the government rebates, the more likely that retrofit investments are undertaken. Cost of investment also appear to play a role in these investment decisions.

The results indicate that such programs can be important tools to induce home energy efficiency improvements, particularly in older homes, and among low income households. Moreover, because the amount of potential energy cost savings is the main factor underlying retrofit investments, and given that specific characteristics of homes with large potential energy cost

[24] Although the square of thermal envelope cost indicator has a positive marginal effect, the overall marginal effect computed as a sum of the marginal effects of the level and 2 times the product of the marginal effect of the square of this variable multiplied by average cost is negative (0.00001*2*41.2472+(-0.00278) = -0.002).

savings are known, policy makers may wish to design targeted programs towards such homes. The role of financial incentives is clearly discerned.

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Chapter 3

Price-induced Energy Efficiency Improvement in Canadian manufacturing

3.1 Introduction

In this study, we consider a new approach to the estimation of price-induced energy efficiency improvements using Canadian manufacturing sector data. Our approach considers forecasts of world oil prices as an important factor taken into consideration by firms when deciding on the implementation or investment energy efficiency improvements. We exploit the fact that forecasted world oil prices that are used in making decisions to invest in energy efficiency are only weakly correlated to realized energy prices. This suggests that price-induced energy efficiency improvements are better estimated using forecasts that businesses consider while making the decision to invest in energy efficiency.

It has long been recognized that relative factor price changes affect energy intensity, a proxy used to indicate energy efficiency, in two ways. The first is through the substitution effect. An increase in actual energy price relative to labour cost, for example, may result in a reduction in energy intensity if energy and labour are substitutes in production. This will simply reduce both energy and labour utilization if the two inputs are complements. These effects are estimated using actual prices or costs. Another mechanism for energy efficiency improvement is through technical change resulting from either the purchase of new equipment embodying energy efficient technologies or by making innovations. Both of these decisions are based on calculation of the present value of net benefits associated with the investments.

Our approach is based on the idea that investment decisions regarding the adoption of new energy efficient technologies, R&D undertakings, and retrofits are based on a firm's expectations of the associated net benefits, with these benefits accruing from the future stream of energy cost savings. In making such decisions firms weigh the expected discounted present values of the benefits against the upfront implementation costs. The higher are the expected energy prices, the larger will be expected benefits of energy efficiency investments. To this effect, the relationship between energy efficiency and prices for most firms in the manufacturing sector is one where businesses invest in energy efficiency capital (purchase of new equipment or retrofitting of existing capital or investment in energy knowledge (R&D) based on comparing the expected discounted lifetime flow of benefits arising from energy savings to the costs of the investments. The expected flow in benefits will be a function of expected energy costs. In this framework, energy efficiency improvement decisions are based on expected energy prices rather than the yet to-be-observed prices.

Firm-level expectations regarding future paths of energy prices are assumed to be formed, at least partially, on publicly available forecasts of the world oil price. This suggests that modeling actual energy efficiency using actual energy prices reflects actual behaviour only to the extent that the various forecasts that are used as the basis for investment decisions are strongly correlated to the actual prices. A comparison of actual prices to forecasts, however, reveals that there is at best a weak correlation. In particular, comparing the various forecasts released by the Energy Information Administration‘s (EIA) annual energy outlook, and previous to that by the National Petroleum Council, that are the most widely used for policy making and investment plans (Winebrake and Sakva, 2006), to the realized refiner acquisition spot prices, we observe that there is a significant difference between the historical realized and forecast energy prices. As shown in Figure 3.1 (see section 3.2), realized oil prices increased significantly during the oil prices shocks of the 1970s, declined during the early to mid 1980s, remained somewhat stable until late 1990s, after which it started increasing again. The forecast oil price, however, does not exhibit such big jumps.

This does not mean actual energy prices are irrelevant, however, in terms of a firm's energy use. Energy efficiency improvement constitutes one of the factors affecting energy intensity (the ratio of energy used to output produced), the others being factor substitution, structural changes, and changes in the composition of fuel used (Kaufmann, 2004). Factor substitutions are driven by changes in actual relative factor prices. The divergent trends in actual and forecast oil prices, therefore, enables us to differentiate direct "expected price"-induced energy efficiency improvements from substitution effects related to actual energy prices. Note that there could also be price-independent technical change that affects energy efficiency. One example is learning-by-doing.

The key to our study is the observation that there are marked differences between the trends in actual energy prices that are relevant for analyzing substitution effects and the forecast world oil prices upon which businesses form their expectations about future energy prices and, therefore, are relevant analyzing price-induced energy efficiency improvements. In particular, using the Canadian KLEMS data set, along with forecasts of world oil prices, we examine the responsiveness of energy intensity to current and expected future energy prices for Canada's manufacturing sector and its major sub-components. To this end, a system of equations for 10 major manufacturing sector industry groups is estimated, with attention paid to possible endogeneity problems through the use of instrumental variable techniques.

Several previous studies have focused on the relationship between energy intensity and energy prices (e.g. Kaufmann, 2004; Metcalf, 2008; Lescaroux, 2008).[1] These studies do not, however, highlight the mechanisms by which prices improve efficiency, nor do they attempt to separate out changes in energy intensity resulting from energy efficiency improvements driven by expected energy prices from substitution effects driven by changes in relative prices. Metcalf and Lescaroux, in particular, treat changes in energy intensity within a sector as efficiency changes, interpreting the coefficient of the price in the decomposed "efficiency index" as the efficiency-inducement effect of price changes.

Hogan and Jorgenson (1991) and Sanstad et al. (2006), on the other hand, also incorporate technical change in their analysis with the assump-

[1] Metcalf (2008) and Lescaroux (2008) measure energy efficiency by decomposing energy intensity into efficiency and other components using the index decomposition methods discussed in Ang and Zhang (2000); Ang (2005); Liu and Ang (2007) ; and Boyd and Roop (2004). Kaufmann (2004) focuses on existence of long-run relationship (co-integration relation) between energy intensity and energy prices.

tion that it is exogenous and hence energy efficiency improvements are price-independent. Although recognizing that energy efficiency can be affected by technical change in addition to price induced substitution is one step forward, treating technical change as exogenous is a restrictive assumption. Fisher-Vanden et al. (2004) include R&D expenditure instead of a time trend in order to account for technical change in their model of energy intensity. This can be seen as an improvement upon the studies that represent technical change using a time trend. There is a possibility, however, that R&D could be endogenous and/or an imperfect proxy for energy-related technical change.

Popp (2001) constructs an index of the stock of energy knowledge based on patent counts, and uses this index as a proxy for technical change in his model of energy intensity. Patents are found to be positively related to energy prices in Popp (2002). Thus, the energy knowledge stock used in the energy intensity equation is assumed to reflect price-induced technical change, allowing the interpretation of his coefficients on technical change index as capturing price-induced energy efficiency improvement.

Energy prices affect efficiency through both invention (R&D activities) and adoption decisions of agents. That is, firms may purchase machines that already embody new energy-efficiency technologies and this would not necessarily be reflected in the firm's R&D spending (Stoneman, 1987). There is empirical evidence confirming that energy prices can induce adoption of energy efficient equipment. For example, Newell et al. (1999) provide empirical estimates of the effect of energy price on adoption of energy efficient equipment and appliances. Furthermore, patenting approximates actual innovations only with substantial error margins (Jaffe et al., 2003) and, therefore, provides an imperfect measure of technical change. What we can conclude from this observation is that using these proxies may not fully capture efficiency-inducing effects of energy prices.

To the extent that price-inducement works through more than one channel, one needs to either be able to take into account all the possible variables that are induced by energy price changes or the price change itself. In this respect, Sue Wing (2008) constructs an alternative index of the stock of energy knowledge based on cumulative energy price increases, using the same general formula as Popp (2001).[2] Constructing a proxy for the stock of energy knowledge based on cumulative energy price increases amounts to assuming that every increase in energy price contributes to this stock. Moreover, when this proxy is included in an energy intensity equation, its coefficient might simply pick the asymmetric effect of energy price increases, as has been suggested, for example, by Adeyemi and Hunt (2007) who conclude that the inclusion of cumulative increases in energy prices in an energy demand equation does not substitute for the inclusion of a proxy for technical change.

In a related study, Linn (2008) models energy efficiency improvement via price-induced adoption of energy efficient technologies under the assumption that new firms have the highest probability of adopting any given new technology. An implication of this assumption is that the magnitude of the effects of energy price changes depends on the age of a firm. The difference between the magnitude of the coefficients on energy price for new and old firms is attributed to price-induced adoption of new technologies and thus measures price-induced energy efficiency improvements. Estimates show that price induced energy efficiency improvement is very small. This small magnitude could, however, be due to the assumption that incumbent firms do not adopt new technologies, with the effect of price on their energy intensity working entirely through a substitution effect.

What is evident from Linn's results and other studies is that the estimation of the extent of price-induced energy efficiency improvements is a complex matter. A major difficulty arises from the fact that, in addition to the substitution effects, price changes can induce energy efficiency via a variety of channels that result in technical change.[3] Estimating energy intensity as a function of actual energy price lumps these various effects of energy price together, even when a time trend is included in an attempt to capture technical change.

[2] The stock of energy knowledge is given as

$$\int_{o}^{\infty} \pi_{Eis} \exp(-\delta_{1i})(1-\exp(\delta_{2i(s+1))} ds \; where \; \delta_{1i} \; and \; \delta_{2i(s+1)}$$

are decay and diffusion rates of knowledge. The equation used in Sue Wing is adopted from Popp (2001), the main difference being that Popp's estimated knowledge stock is based on patent counts which he shows to be related to energy prices in Popp (2002).

[3] Substitution effect refers the the possibility that relative energy price increases could lead to substitution of other factors for energy.

Our approach is different in an important way. We exploit the fact that expected prices provide a driving force for efficiency-improving technical change and assume that forecasts of oil prices proxy these expectations reasonably well. These forecasts are weakly correlated with the realized energy price trends, implying that we can include both forecasted and realized prices in our energy intensity model. Our approach is based on the observation that decisions regarding investments in energy efficiency improvements are based on expected energy prices, rather than realized energy prices and that the realized prices are the effects of factor substitution.

In particular, we estimate two specifications of a model of energy intensity for manufacturing industries. The first is a traditional specification in which a time trend is the only term used to capture the effects of energy efficiency improvements (technical change). Our second specification accounts for both price-induced and autonomous energy efficiency improvements. That is, time trend is still relevant after a variable capturing price-induced efficiency improvements is included because there are efficiency improvements that are autonomous by nature, e.g. learning by doing. The results suggest that a failure to take price-induced energy efficiency improvements into account in energy intensity models leads to misidentification of elasticity coefficients. Particularly, we observe that the coefficient estimates for the autonomous time trend are similar while the substitution effects vary across the two specifications.

Model estimates for specific manufacturing sub-sector reveal some interesting results. For example, technical change is energy-using in the Petroleum Refining and Coal Products sub-sector and appears to be entirely induced by expected changes in oil prices. This is consistent with general intuition, as expected increases in energy prices translate into expected increases in profitability, thereby reducing incentives to improve efficiency. On the other hand, the steep decline in energy intensity in the Computer and Electronic Products sub-sector is entirely autonomous. This can be interpreted in terms of the effects of learning-by-doing characteristics of this sector. Moreover, we do not observe statistically significant technical change in the Primary Metals Manufacturing sub sector, similar to the results observed in Popp (2002).

The remainder of the paper is organized as follows. In Section 3.2 we examine several stylized facts regarding (i) the patterns of energy prices and energy price forecasts; (ii) energy efficiency trends in the aggregate Canadian manufacturing sector; and (iii) energy efficiency trends in subsectors. We specify our empirical model in Section 3.3. In Section 3.4, we discuss the data and econometric issues. Results are presented and analyzed in Section 3.5. Section 3.6 concludes.

3.2 Stylized Facts and Background Information

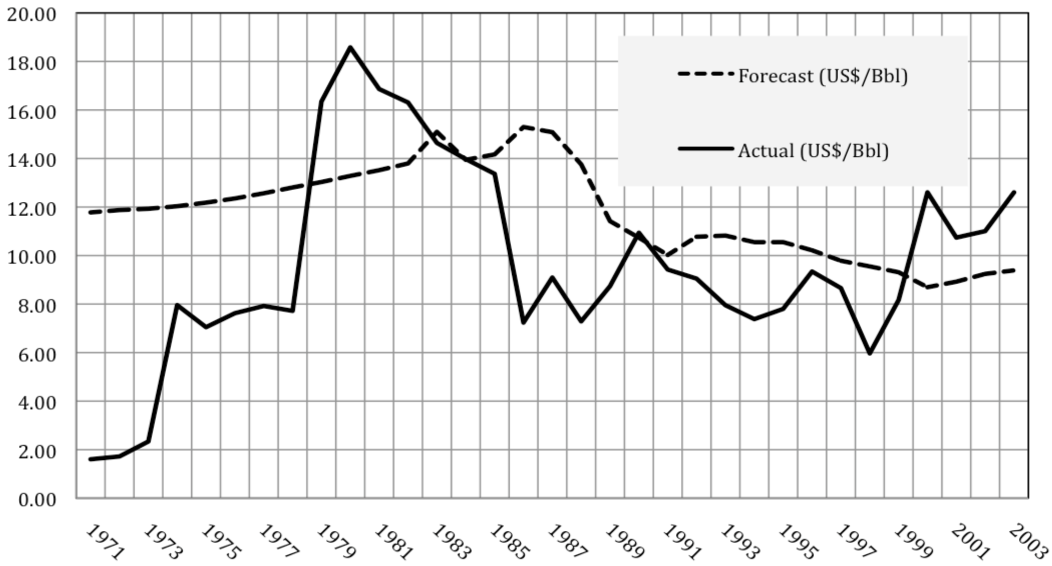
Over the past few decades, there have been substantial movements in energy prices, forecasts of energy prices, and energy use. Although not the only energy input, we focus on oil price movements since oil is a major energy input and, as a fossil fuel, its cost to final users would be affected by potential environmental policies such as a carbon tax.

Trends in actual and forecast oil prices

As illustrated in Figure 1, real world oil prices have undergone periods of rapid increase, periods of rapid decrease and periods of relative stability over the past few decades. Expectations of these prices, as captured through forecasts made by the Energy Information Administration, and previous to that by the National Petroleum Council (NPC), have been markedly more stable (Energy Information Administration, 2006; 1982; National Petroleum Council, 1973).[4] Note that, with the exception of the late 1970s / early 1980s and the most recent period, these forecasts have tended to be above the prices realized in the market. It can be reasonably argued that firms will make short-term substitution decisions based on current prices and long-term capital acquisition or retrofit decisions based on forecast prices. Oil, of course, is not the only energy input for firms. Non-electric sources of energy accounted for between 55 to 94 % of total

[4]Forecasts are averages of projections made during the previous five years. For example, the forecast for 1990 is the average of projections made in 1989, 1988, 1987, 1986 and 1985. Forecasts prior to 1983 are compiled from National Petroleum Council (NPC, 1973), which provides forecasts of wellhead average revenue required for oil production under various economic and rates of returns assumptions. We computed averages of all possible scenarios (five scenarios for each year). This forecast is available for 1971 – 1985. The annual energy outlook published by the Energy Information Administration provides forecasts since 1982. We used the average variation between the two forecast series during the overlapping period (1982 -1985) to adjust the NPC forecast because the EIA projects refiner acquisition costs.

Figure 3.1: Trends in Actual And Forecast Real Oil Prices of Crude Oil*



* The plots represent nominal value converted to constant 1970 dollars using wholesale price index. Actual prices are obtained from EIA, `http://www.eia.doe.gov`. For source of forecasted price, see footnote 3. All values are expressed in terms of the Canadian dollar.

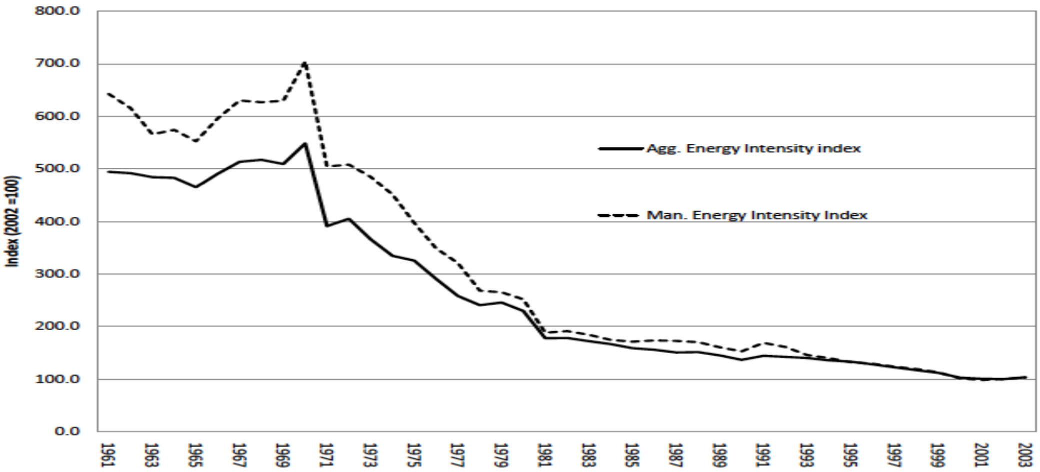
energy use during the 1990 - 2007 period, with the exception of one group where it accounts for only 34% (See Appendix B, Table B.1 column 9). This variation in the relative importance of oil in the energy mix suggests that it is likely that sub-sectors will react to price signals, including those implied by policy changes, differently. That is, the extent to which oil plays a role in the production process for various sectors will determine how much any particular firm will pay attention to oil prices, as opposed to those for other energy inputs.

Energy use trends in the Canadian manufacturing sector

In this study, we focus on the Canadian manufacturing sector. The contribution of this sector to energy consumption and GHG emissions is significant. The manufacturing sector accounted for over 27 percent of final energy consumption in Canada over the 1960 - 2005 period (International Energy Agency, 2004).[5] Although energy use in the manufacturing sector increased from 20830 Ktoe in 1960 to 53622 Ktoe in 2005 (an average an-

[5]Long-range data on quantities of energy use by sector are obtained from IEA, Energy Balances of OECD countries, as KLEMS data provides energy consumption in quantity indexes.

Figure 3.2: Trends in Aggregate and Manufacturing Energy Intensity Indexes (Energy Quantity Index/Output Quantity Index)



Source: Computed from Canadian KLEMS

nual growth rate of 1.75 percent), its share has experienced a decline over the years, falling from 31.34 percent in 1960 to 21.4 percent in 2005. When viewed in relation to the average annual growth rate of manufacturing sector GDP, which, according to the KLEMS data, was more than 4 percent over the 1962 - 2003 period, the percentage increase in manufacturing energy use during the same period suggests that there has been a decline in energy intensity. This is clearly shown in Figure 3.2 which compares the trends in overall and manufacturing energy intensity. Energy intensity of the Canadian economy appears to have experienced a structural break following the oil price shocks of early 1970s, declining precipitously until the early 1980s. During this period, the manufacturing sector energy intensity caught up with the rest of the economy, suggesting that more than a proportionate decline was achieved in this sector.

Note that this intensity trend captures both structural change (composition effect) and energy efficiency effects. In general, a comparison of technical change measured by growth in total factor productivity and the rate of change in the undecomposed energy intensity suggests that technical change is energy-saving in Canadian manufacturing during the period after 1974 (Figure 3.3). After excluding the composition effect, we observe in Figure 3.7 that energy intensity declined during the period following the 1973-74 oil price shocks but then increased slightly during the late 1980s, corresponding to a period of low world oil prices. Appendix B1 shows that the composition of the manufacturing sector underwent changes as shown by the trends in the GDP shares of the sub-groups. It appears, therefore,

Figure 3.3: The Relationship Between Growth Rates in TFP and Energy Intensity

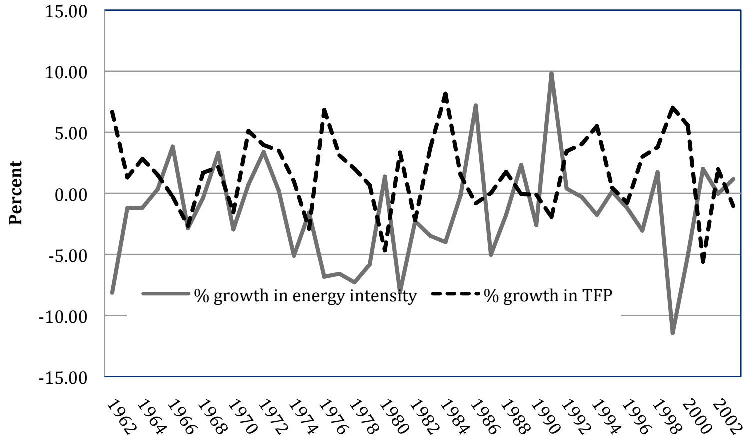
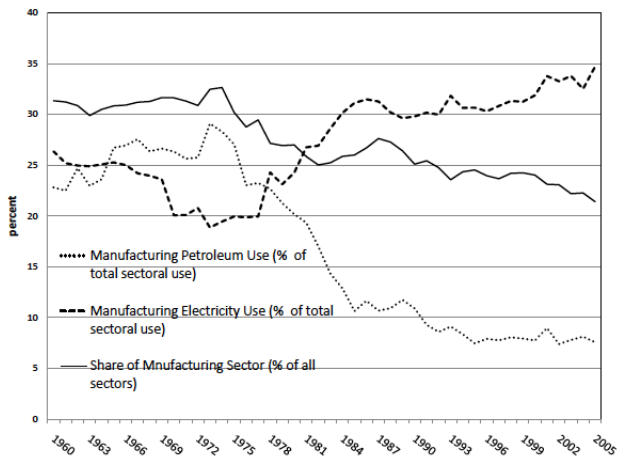


Figure 3.4: Trends in Canadian Manufacturing Energy Use Patterns



Source: IEA:Energy Balances of OECD countries

that the continued declined we observe in the undecomposed energy intensity trend (Figure 3.2) during late 1980s could result from structural changes in favour of less energy intensive industries. In Appendix B1 for example, we see that the share of the Pulp and Paper sector, a sector that is known for high energy intensity, has declined since 1976 in general, although there were occasional years with increases in the shares. This may have contributed to the decline in manufacturing sector energy intensity due to composition effects.

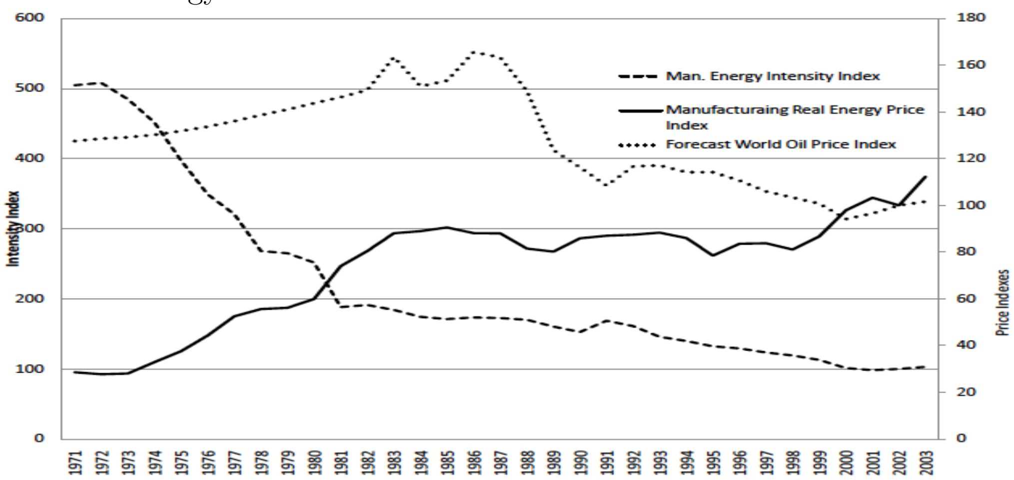
An important structural shift in the manufacturing sector can be seen in terms of fuel switching. As can be seen in Figure 3.4, the share of petroleum products in Canadian manufacturing sector energy use has declined while the share of electricity has increased since 1972. Over this period the share of the manufacturing sector in total energy use has experienced a decline. Note that the turning point in the share of electricity coincided with the early 1970s oil price shock which is shown in Figure 3.1. What we observe here is that the increased reliance on electricity might have contributed to the less than proportionate increase in overall energy use in the manufacturing sector. Meanwhile, the KLEMS data show that the share of manufacturing in the aggregate value of production has declined only modestly (from 40 percent to slightly below 35 percent) since the mid-1970s. We observe in Figure 3.2, on the other hand, that the manufacturing sector energy intensity declined more rapidly as compared to the overall economy.

To view the trends within the context of activities targeting energy efficiency, note that there have been concerted efforts by the industry group (CIPEC) in partnership with the federal government to promote energy savings. About 98 percent of manufacturing establishments (industry associations and companies) are covered by CIPEC, which was established in 1975 (CIPEC, 2007). The network helps members to reduce energy intensity by creating awareness of available options for reducing costs via improvements in energy efficiency. This is done mainly through information dissemination programs such as "dollar to $ense" workshops and energy audit programs. More recently, the federal government has begun to offer financial incentives through the ecoEnergy retrofit incentives for industry program, put in place in 2006. The federal government, in partnership with CIPEC, planned to provide $1 billion in funding to the industry sector over the period April 1, 2007 to March 31, 2011 period (`www.ecoAction.gc.ca`). Meanwhile, the Canadian economy continues, however, to be characterized by high energy intensity when compared to other industrialized countries (Natural Resource Canada, 2006). Thus, there is great interest in the achievement of further improvements in energy efficiency.[6]

The fact that the major incentive to implement actions of energy saving, as promoted by CIPEC, is cost savings, it is of interest to see if the data reveal a relationship between energy intensity and energy price trends. There are two possible ways by which energy prices affect energy intensity: through substitution of other factors (labour, capital, and materials) for energy and through pure efficiency gains resulting from energy

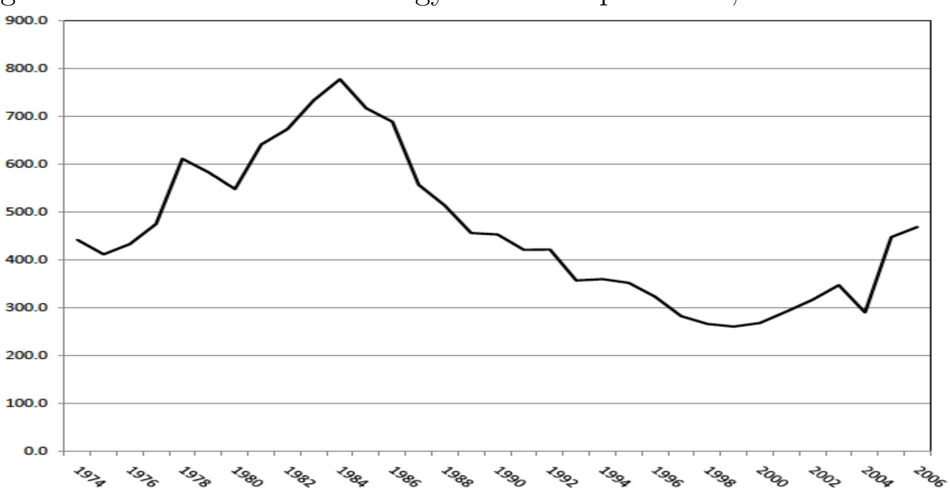
[6] A detailed account of policy measures and proposals in Canada is presented in a commentary by Jaccard et al., (2006).

Figure 3.5: Trends in Energy Intensity, Forecast, and Historical Actual Real Energy Prices



Source: Actual price and energy intensity are computed from Canadian KLEMS data; forecast world oil prices are as described in footnote 3.

Figure 3.6: Total Canadian Energy RD&D Expenditure, Million 2006 US$



Source: International Energy Agency

conservation by implementing best practices and management in resource use and installing more efficient processes and equipment. By plotting real energy cost[7], we observe that there appears to have been a role played by energy costs. As shown in Figure 3.5, we see that the energy intensity and energy prices follow opposite trends. Energy intensity has declined by over 71 percent from 1962 to 2003 (with an average annual decline of about 1.72 percent) while real energy costs have increased by an average of 2.72 percent per annum. We also see from Figure 3.5 that, at times, energy intensity and forecast oil prices have moved in opposite directions. In more recent years, however, they have tended to move in the same direction. As evidence that the price effect does not work solely through substitutions but also by inducing technical change, we observe in Figure 3.6 that the amount of expenditure on energy Research, Development, and Demonstration (RD&D) in Canada increased from the mid-1970s to the mid-80s, followed by several years of decline, again showing an increasing trend recently. This follows the same general patterns as oil prices.

Disaggregated energy use trends in the Canadian manufacturing sector

Trends of energy use in the manufacturing sector are by no means uniform. The manufacturing sector comprises a variety of activities, each with its own set of available production processes and possibilities for improving energy efficiency via the adoption of new technologies, the retrofitting of existing capital, et cetera. Appendix B, Table B.1 looks at a variety of production and energy-related characteristics over the 1990 to 2007 period for the major industry groups within the manufacturing sector. We see from Column 5 that some sub-groups within the manufacturing sector, such as Textile Products and Clothing, have been characterized by growth rates of energy use per unit of output of almost -6 percent. For Wood Products, however, the rate is +3 percent. Looking at Column 8, we observe that the energy intensity for Pulp and Paper is more than five times the average. These statistics indicate that it will be important to model changes in energy intensity in a way that allows for differences across sub-sectors, rather than ascribing the same overall sectoral behaviour to all sub-sectors.

[7] This is calculated as the of the manufacturing energy price index to the manufacturing output price index from KLEMS data

The mix of energy sources also differs across sub-sectors. In Column 9, we observe that non-electric sources of fuel, which consist mainly of petroleum products, account for the largest share among energy sources in the manufacturing sector. However, there is significant variation across the sub-sectors, with the largest share being as high as 94% for Petroleum and Coal Products and the smallest share 37% for Computer and Electronic Products. This variation in the importance of petroleum products as a source of energy implies that the sub-sectors will likely react differently to changes in actual and expected oil prices. Information on trends in capital - energy, labour-energy, and materials-energy ratios computed from the KLEMS data set also indicate that the rates of change in these indicators of factor substitution vary across the subgroups (Appendix B, Table B.2). This could be explained by differences in their technologies, and therefore the set of feasible adjustments that are available in a particular sub sector.

3.3 Model Specification

We model price-induced energy efficiency improvement under the assumption that expected increases in energy prices induce technical change. Thus, we begin by defining the relationship between factor efficiency improvement and technical change. Factor efficiency improvement due to technical change is defined as the rate of decline in factor intensity due to technical change. Suppose X_i is the quantity of the i^{th} factor, Y is output, and T represents technical change. Assuming that technical change evolves exogenously, we can express factor efficiency improvement, as the negative of the partial derivative of the natural log of factor intensity with respect to technical change:

$$\tau_i = -\frac{\partial ln(\frac{X_i}{Y})}{\partial T} = -\frac{\frac{\partial(\frac{X_i}{Y})}{\partial T}}{\frac{X_i}{Y}}, \tag{3.1}$$

When X_i is the quantity of energy used in the production process, this is known as autonomous energy efficiency improvement. If technology is endogenous, the factor efficiency improvement is instead given by:

$$\tau_i = -\sum_j \frac{\partial ln(\frac{X_i}{Y})}{\partial T} \cdot \frac{\partial T}{\partial Z_j}, \tag{3.2}$$

where Z_j is a vector of the factors driving technical change.

In evaluating induced energy efficiency improvement, it is important to focus on technological change that is particularly related to energy. Thus, we assume that technical change is factor-specific. In line with Equation (3.1), we assume that factor $i's$ efficiency improvement is positively related to technical change specific to that factor according to a simple relationship:

$$\tau_{it} = \delta_0 + \delta_1 T_{it}, \tag{3.3}$$

where τ_{it} is factor i efficiency improvement at time t; and T_{it} is factor i-augmenting technical change at time t; and $\delta_1 > 0$. Technical change, T_{it} is a function of $g(\chi_j)$ in which case

$$\tau_{it} = \delta_0 + \delta_1 g(\chi_{jt}), \tag{3.4}$$

where $g(.)$ is a function relating factor i-augmenting technical change to its drivers.

Focusing on energy efficiency improvement, our key assumption is that expected energy price changes comprise a major component of χ_{jt}; that is, we assume that $\chi_{jt} = g(\{P^e_t\}^t_{t-i})$ where $\{P^e\}^t_{t-i}$ is a series of time t energy price forecasts announced during previous periods. With this argument, we specify a simple relationship between energy efficiency improvement and the history of energy price forecasts as follows[8]:

$$\tau_{E,t} = \delta_0 + \delta_1 \left(\sum_{i=0}^{t} \gamma_i P^e_{t-i} \right), \tag{3.5}$$

In this specification, we assume that firm decision to invest in energy efficiency considers energy price only. It is possible that firms also consider future labour costs into account which means we may have to also account for expected wages in the same fashion we are considering expected en-

[8]The equation is specified assuming that $g(\{P^e_t\}^t_{t-i}) = \sum \gamma_i P^e_{t-i}$

ergy prices. A more complete examination of appropriate lag lengths for particular sub-sectors is left for future work.

Two key points that we have to consider from a modeling point of view are (i) the derivation of estimates of factor efficiency improvements as shown by Equation 3.2 requires that we model factor intensity (factor demand); and (ii), empirical factor demand models have to be motivated by a "well-defined" function representing the production technology - cost or production function. Although the translog cost function is popular for this purpose, we adopt a generalized Leontief (GL) cost function as this allows us to represent demand functions in terms of factor intensities ($\frac{X_i}{Y}$).

Consider the generalized Leontief cost function for a production process using n-inputs (Diewert, 1971) under the assumption that technology is factor-augmenting. In the context of a cost function, including factor-augmenting technical change is handled by dividing factor prices by respective factor efficiencies (Kumbhakar, 2002). The cost function, thus, becomes:

$$C(Y,\mathbf{P}) = \mathbf{Y}\left[\sum_{\mathbf{i=1}}^{\mathbf{n}}\sum_{\mathbf{j=1}}^{\mathbf{n}}\beta_{\mathbf{ij}}\left(\hat{p}_i\right)^{\mathbf{0.5}}\left(\hat{p}_j\right)^{\mathbf{0.5}}\right] = Y\left[\sum_{i=j}^{n}\beta_{ii}\hat{p}_i + \sum_{i\neq j}^{n}\sum_{j\neq i}^{n}\beta_{ij}\left(\hat{p}_i\right)^{0.5}\left(\hat{p}_j\right)^{0.5}\right] \tag{3.6}$$

where Y is output, and $\hat{p}_i$ and $\hat{p}_j$ are p_i/τ_i and p_j/τ_j, respectively. Symmetry is assumed such that $\beta_{ij} = \beta_{ji}$. It is also assumed that, with energy being the i^{th} input, the prices of all other inputs are "quality-adjusted" such that the $\hat{p}_j s$ are actual prices. This is true given that factor prices are given as prices for the respective factor services. For energy, however, the price data are expressed in terms of purchase cost.[9] Taking this into account and applying Shephard's lemma gives us the following energy intensity equation:

$$\frac{E}{Y} = \beta_{EE}\tau_E^{-1} + 0.5\sum_{j}^{n}\beta_{Ej}\left(\frac{p_E}{\tau_E}\right)^{-0.5}\left(\hat{p}_j\right)^{0.5}, \tag{3.7}$$

where $\hat{p}_j$ are prices of K, L, M, and S, and p_E is the price of energy. Equation 3.7 suggests that the factors affecting energy efficiency enter the energy

[9] Data on measurements of factor productivity such as the Canadian KLEMS data set normally present labour and capital prices as the costs of the services provided by these factors, inherently incorporating quality or factor efficiency.

intensity equation in two ways: (i) directly according to the first term; and (ii) as a factor multiplying the relative factor prices. The first term indicates the negative relationship between energy efficiency improvement (τ_E) and energy intensity. Thus, expected energy prices have a negative effect on energy intensity through induced efficiency improvement as captured by this first term. Substituting Equation (3.5) and rearranging terms gives us:

$$\frac{E}{Y} = \beta_0 + \sum_{i=0}^{t} \beta_i P_{t-i}^e + 0.5 \sum_{j=1}^{n} \sum_{i=0}^{t} \beta_{eEj} P_{t-i}^e \left(\frac{\hat{p}_j}{p_E} \right)^{0.5} + 0.5 \sum_{j}^{n} \beta_{Ej} \left(\frac{\hat{p}_j}{p_E} \right)^{0.5}, \tag{3.8}$$

$\beta_i < 0$ & $\beta_{eEj} < 0$ iff $\beta_{Ej} > 0$. The second and the third terms capture the effects of expected energy prices included to capture price-induced energy efficiency improvements.

To compare our specification to approaches which assume exogenous technical change, consider the GL cost function without the modifications just introduced:

$$C(\mathbf{P}, Y) = Y \left[\sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} p_i^{\frac{1}{2}} p_j^{\frac{1}{2}} + \sum_{i}^{n} \beta_{it} p_{it} T \right], \tag{3.9}$$

where T is a time trend representing overall technical change. This yields a system of factor intensity equations that can be expressed given as functions of prices and the level of technology given by the time trend:

$$\frac{X_i}{Y} = \sum_{j=1}^{n} (\frac{1}{2}) \beta_{ij} p_j^{\frac{1}{2}} p_i^{-\frac{1}{2}} + \beta_{it} T, \tag{3.10}$$

So that the energy intensity equation becomes:

$$\tfrac{E}{Y} = \beta_{EE} + 0.5 \sum_{j=1}^{n} \beta_{Ej} \left(\tfrac{P_j}{P_E} \right)^{0.5} + \beta_{TE} T, \tag{3.11}$$

for j = K, L, M, and S.

Equation (3.8) leaves out price-independent efficiencies, while Equation (3.11) assumes that all technical change is totally price-independent.

More realistically, however, energy efficiency improvements can be attributable to both. We therefore specify our estimation equation for energy intensity as a function of actual factor prices to account for substitution effects, a time trend to account for any autonomous efficiency improvement, and expected energy prices to account for price-induced energy efficiency improvements.

3.4 Data and Estimation Strategy

In this section, we discuss the data used for estimating our models and issues related to the methods of estimation.

3.4.1 Data

The Canadian KLEMS (K -capital, L - labour, E-Energy; M - Materials; and S - Services) database released by Statistics Canada in 2008 contains a rich set of detailed industry data. It includes industry- specific output quantity and price indices; cost shares for each input; input quantity indexes; dollar values for outputs, output price indexes, and productivity indexes for the period 1961-2003. Although data are presented using both the Standard Industry Classification (SIC) and the North American Industry Classification Schemes (NAICS), data for the former classification end in 1997. There are 44 manufacturing industries in Canada, according to the NAICS classification scheme.

We aggregate the 44 industries into 20 major industry subgroups (Table 3.1), consistent with NAICS 3-digit classification. Aggregation requires the use of weights. In line with the index decomposition approaches, it is possible to insure that the weights themselves do not play part in the trends of the energy intensity so that the aggregate index we obtain reflects changes in industry-level energy intensity alone. One particular method is to use the base year value-added shares of the industries for the sub sector they belong to (e.g. International Energy Agency, 2004).

Table 3.1: Summary Statistics for Variables Computed from KLEMS Data (1961 - 2003 Averages), 2002 = 1

Industry group	EI	$(PK/PE)^{0.5}$	$(PL/PE)^{0.5}$	$(PM/PE)^{0.5}$	$(PS/PE)^{0.5}$	Average Share in manufacturing value added (%)
Food (311)	1.39	1.05	1.23	1.09	0.88	10.7
Beverages and Tobacco (312)	1.32	0.96	1.21	1.03	1.02	3.9
Textile and textile product mills [31A]	1.41	0.93	1.51	1.07	0.91	2.1
Clothing manufacturing [315]	1.21	1.08	1.37	1.11	0.85	3.2
Leather and allied product manufacturing [316]	1.27	1.22	1.25	1.12	0.86	0.8
Wood product manufacturing [321]	1.34	0.88	1.24	1.09	0.91	5.3
Pulp, paper, and paperboards mills; and converted paper products (322)	1.24	1.09	1.29	1.12	0.85	8.6
Printing and related support activities [323]	1.12	0.86	1.14	1.07	0.88	2.9
Petroleum and coal products manufacturing (324)	0.46	0.71	0.86	0.97	1.15	1.7
Chemicals (325)	1.30	1.04	1.15	1.07	0.91	8.4
Plastic and rubber (326)	1.60	0.93	1.16	1.02	0.97	3.6
Cement and Misc. non-metalic (327)	1.70	0.94	1.30	1.07	0.91	3.4
Primary Metal (331)	1.40	0.80	1.29	0.97	1.07	7.6
Fabricated metal products (332)	1.47	0.93	1.26	1.16	0.83	6.9
Machinery (333)	1.78	0.95	1.10	1.07	0.93	5.9
Computer and Electronic Productt (334)	23.90	4.75	5.09	1.05	0.96	4.8
Household appliances and electrical equipment and components (335)	1.95	1.36	1.24	1.10	0.87	3.5
Transport Equipment. (336)	2.12	0.96	1.12	1.07	0.93	12.8
Furniture (337)	1.66	0.88	1.17	1.05	0.96	2.2
Miscellaneous (3390)	1.84	0.86	1.30	1.09	0.92	1.8
Aggregate Manufacturing	2.04	1.31	1.32	1.07	0.92	100.0

Construction of the dependent variable

We calculate energy intensities for each industry as a ratio of the energy quantity index to the output quantity index ($EI_{it} = \frac{E_{it}}{Y_{it}}$). The aggregation proceeded as follows. Denote the share of industry i value added in manufacturing value added at time t as $s_{i,t}$. Thus, at time t, the energy intensity of a major industry group g is given by $\sum_{i\epsilon g} s_{it} EI_{it}$. According to this equation, major industry group energy intensity changes due to both industry level changes in energy intensity and the composition of the industries. Following the standard decomposition technique and applying the log-mean weights as in Ang (2005), we have the following aggregate energy intensity trend (see Appendix B2 for detail):

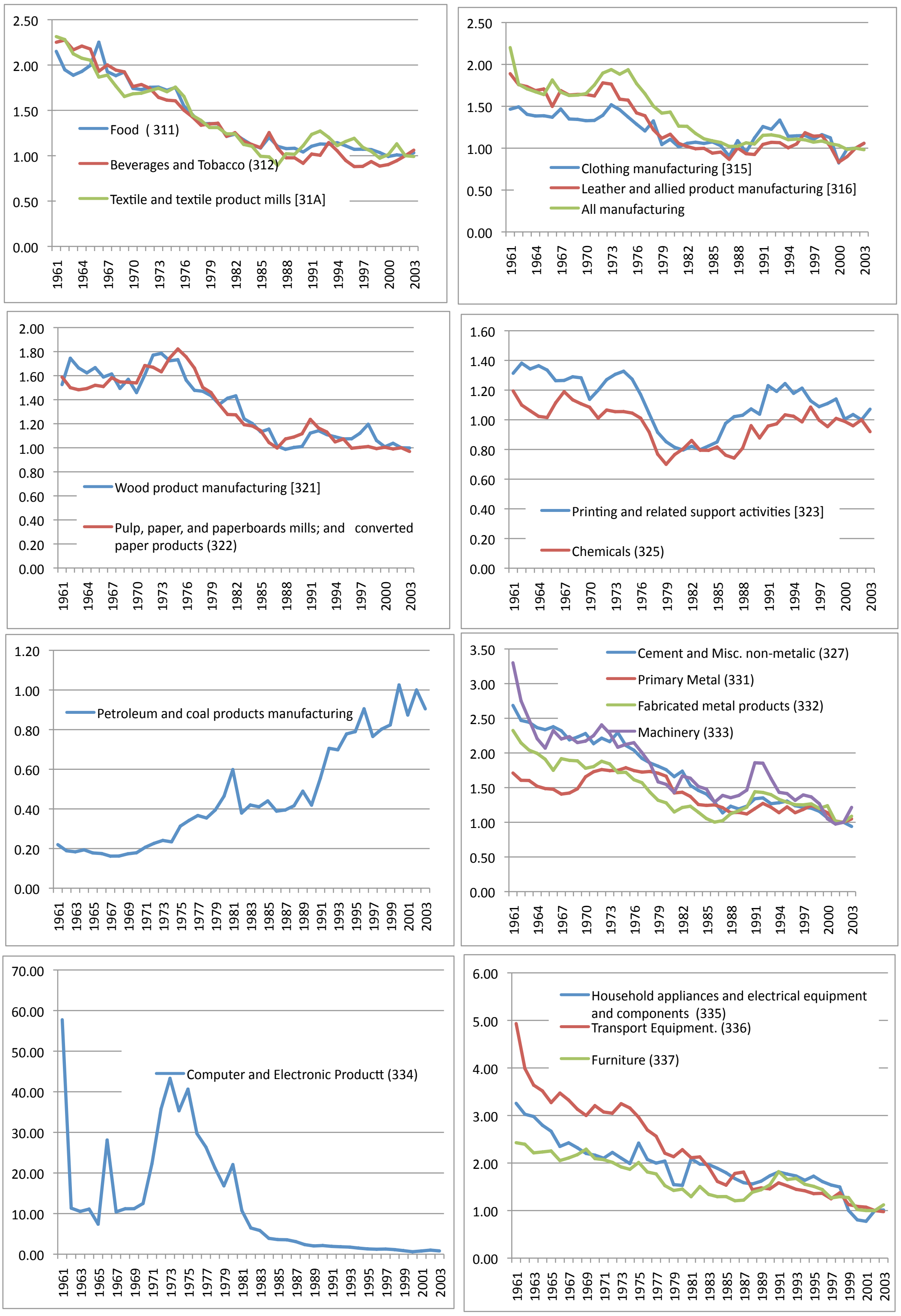
$$EI_{gt} = \exp\left\{\sum_{i\in g} w^*_{it} lnEI_{it}\right\} \tag{3.12}$$

where w^*_{it} is the log-mean weight.

Comparisons of the trends in energy intensities across the groups are provided in Figure 3.7 and Table 3.1.[10] The values in Table 3.1 indicate that the average values of energy intensity during year 1971 - 2005 varied across the sub-sectors. We observe that energy intensities for most industry groups were declining until the late 1980s or early 1990s. Thereafter, we observe that energy intensities experienced modest increases followed by slight decreases during the late 1990s and early 2000s. Notably, the average value for Computer and Electronic Products sub-sector is 23.9, which is several times larger than the values for other sectors. The lowest average value (0.46) was for the Petroleum and Coal Products sub-sector. The trends, however, show that energy intensity declined significantly over the years in the Computer and Electronic Products sub-sector while it was increasing in the Petroleum and Coal Products sub-sector. The average capital- and labour-energy price ratios are very large in the Computer and Electronic Products sub sector compared to the rest of the sub-sectors. A stark difference is seen in the upward trending energy intensity in the Petroleum Refining and Coal mining industries.

[10]Graphs of shares in manufacturing GDP are presented in Appendix B1.

Figure 3.7: Comparisons of Trends in Energy Intensity



Construction of explanatory variables

Data on all historical "current" (as opposed to forecasted) prices are obtained from the KLEMS data set. Group-wise price indices are constructed as a share-weighted sum of the price indices of the industries within each group: $P_{gt}^{i} = \sum_{i \in g} s_{it} P_{it}^{i}$, where P_{gt}^{i} is price of item i (K, L, E, M, S) in group g, and s_{it} is share of industry i GDP in group g GDP.

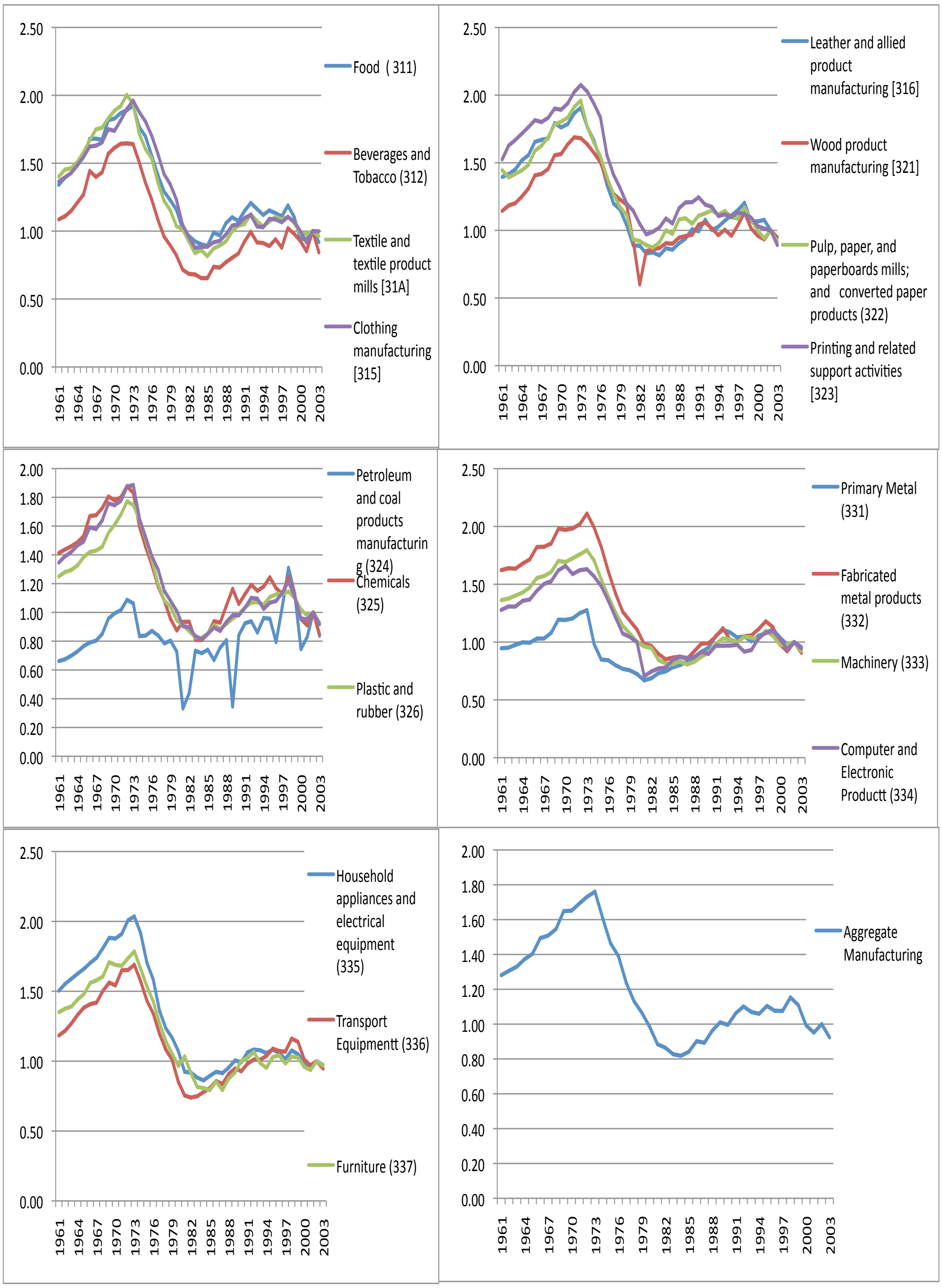
In line with our empirical specification, we use the ratios of the K, L, M, and S prices to that of E. All prices are aggregated from industry data to major industry groups. Sample means of the dependent and explanatory variables computed from the KLEMS data set are presented in Table 3.1 and, in more detail, in Appendices B, Tables B.2 and B.3.[11] We present the ratios of wages to energy prices Figure 3.8. We observe that the ratio follows a clear pattern that it declines during high oil prices, but rises during low oil prices. There is only one exception to this trend, the trend for oil and coal sector. It appears that a decline in oil prices reduces the ratio rather than increasing it, meaning that wages are also declining.

World oil price forecasts are taken from the Energy Information Administration's (EIA) Annual Energy Outlook publications, as they are widely used for policy making and investment plans (Winebrake and Sakva, 2006). The EIA started publishing these Annual Energy Outlooks in 1982. In recent years, the EIA has published evaluations of its forecasts, comparing the forecasts made in various Annual Energy Outlooks for a specific year. In using the forecast prices, it is important to note that we have several forecasts issued for each year as the Outlooks provide (at least) five years of projections. Since we do not know which particular forecasts a business will use in its projections, we take the averages of all the forecasts provided in the available Outlooks. For example, the oil price forecast for 1990 is the average of projections made in 1989, 1988, 1987, 1986 and 1985. The EIA forecast evaluation is useful in this respect as it provides a comparison of Outlooks issued during the previous five years. In particular, we used the information provided in Table 4 of the 2006 issue of the forecast evaluation for years since 1985.[12] The Energy Outlook publication for 1982 is used for the period 1983 - 1984.

[11] Appendix 3 shows the trends in these variables by breaking down the presentation by decade so that we can observe how they evolve over time.

[12] `www.eia.doe.gov/oiaf/analysispaper/retrospective/pdf/0640(2006).pdf.`

Figure 3.8: Trends is Wage-Energy Price Ratio



Forecasts prior to 1983 are compiled from National Petroleum Council (NPC) (National Petroleum Council, 1973) which provides forecasts of wellhead petroleum prices under various assumptions regarding the economy and rates of returns, five scenarios for each year, for the period 1971 - 1985. These are provided in real terms. We convert the NPC forecasts to the nominal values by multiplying them by a wholesale price index given that they were provided in real terms using the same index. Additionally, EIA has provided projections of refiner acquisition costs of petroleum since 1982 (Energy Information Administration, 1982). In order to use these two separate projections, we first compute the average variation between the two forecast series during the overlapping period (1982 -1985) and use the difference to adjust the NPC forecast. That is, we added the calculated average difference between the two series during the overlapping period to the NPC price for the years 1972 - 1981. Our forecast oil price trends, therefore, includes the 'adjusted' NPC projections for the period 1972 - 1981, and the EIA projections thereafter. All nominal price forecasts are converted into domestic currency terms using the Canada-US exchange rate. We then deflate these series by the Canadian wholesale price index to express it in real terms. We construct index of forecast oil price by normalizing the year 2001 value in line with the KLEMS data.[13]

3.4.2 Estimation Strategy

In our empirical model, in order to circumvent multicollinearity problems, we excluded services prices because of its very high correlation with labour and capital prices. Similarly we exclude the materials price because of its very high correlation with the capital prices. The rationale for excluding one of two highly correlated variables in regression analysis is because the two variables essentially convey the same message from a statistical point of view. Including lagged dependent variables on the right hand side to account for the dynamics in the energy intensity trend as in Popp (2001) and Sue Wing (2008), we write our estimation equation as follows:

$$\frac{E_{it}}{Y_{it}} = \gamma_{0i} + \gamma_{1i}\left(\frac{P_{Kit}}{P_{Eit}}\right)^{0.5} + \gamma_{2i}\left(\frac{P_{Lit}}{P_{Eit}}\right)^{0.5} + \gamma_{5i}P_t^e + \gamma_{6i}P_{t-1}^e + \gamma_{7i}T + \lambda_i\frac{E_{it-1}}{Y_{it-1}} + \varepsilon_{it} \quad (3.13)$$

[13]See Figure 1 for the trends in this index

for i = 1, 2, 3,. . ., 20. We compute the price-induced energy efficiency effect as $(\gamma_{5i} + \gamma_{6i})/(1 - \lambda_i)$, and express it as an elasticity by multiplying it by the average ratio of forecast price to respective energy intensities. We compute price-independent (autonomous) energy efficiency improvement as $\gamma_{7i}/(1-\lambda_i)$. We first estimate a traditional model by setting $\gamma_{5i} = \gamma_{6i} = 0$.

Some projects have long gestation period compared to others which means the lag-length of the historical forecast price may vary across the groups we analyze. To account for this variation, we built the forecast price index based on forecasts provided for a particular year during the last five years. We also include one period lag of this index in the estimation equation.[14] In view of the fact that trends for manufacturing sector industries vary widely in terms of their fuel efficiency, their importance in terms of shares in manufacturing GDP, and their dependence on non-electric fuel sources (which is mainly petroleum products) as shown in Appendix B, Table B.1, as well as in terms of the values of energy intensities as shown in Table 3.1, allowing coefficients to vary across sub-sectors is important. We also note that all industries within the manufacturing sector are influenced, possibly to varying extents, by various economic and policy phenomena not explicitly captured in the model, suggesting the likely existence of cross-correlations across the errors in the equations representing the industry groups. In the presence of such correlations, system estimation results in efficiency gains as compared to an equation-by-equation approach (Greene, 2003). Whether a system estimation technique is called for can be tested using a Lagrange multiplier test (Breusch and Pagan, 1980) on the covariance matrix of the residuals. Under the null of no cross-correlations, the LM statistic is distributed as $\chi^2_{((1/2)M\times(M-1))}$ where M is the number of equations.

We employed an Iterative Seemingly Unrelated Regression approach, which enables us to obtain convergence in parameter estimates. This, however, has a cost of leaving out some groups from the system given that the residual variance-covariance matrix computed at each stage has to be positive-definite in order for the iteration to continue to subsequent stages. We encountered problem of non-positive definite variance-covariance matrices at various stages, requiring us to exclude groups that contributed

[14]While most definite results may require further study, the estimation results show that lagged expected price is irrelevant in some groups while it is the lag which matters in other groups. This may explain the variation in gestation period which leads to different planning horizons.

to this problem. Our final results include 11 groups, including the overall manufacturing sector. Given that we have results for the overall manufacturing sector, the other 10 groups are enough to shed light on possible variations in the empirical results across the groups. Moreover, the groups included represent over 60% of manufacturing value added and are large sub-sectors in terms of energy consumption. The calculated value of the Lagrange multiplier statistic is $\chi^2_{(45)} = 379.8$ which is significant at 1% level of significance, suggesting the desirability of system estimation.[15]

We conducted diagnostic checks for serial correlation and heteroskedasticity for each of the equations that enter in our iterative system regression. We carried out Breusch-Godfrey test for higher order serial correlation along with its complementary test, Durbin's Alternative test, that is robust to heterskedasticity. We present the results for the traditional specification in Table 3.2. Heteroskedasticity is detected in Pulp and Paper, Cement, and Primary Metal Manufacturing whereas first order serial correlation is detected in Computer and Electronic Equipment. Serial correlation of higher order is detected in Transport Equipment Manufacturing.

Owing to these diagnostic test results, we follow an estimation strategy in which we use system estimation for the equations that are free from both serial correlation and heteroskedasticity problem and separately estimate the models for the ones with heteroskedasticity or serial correlation. We use Ordinary Least Square with robust standard errors for the cases with heteroskedasticity problems, while the Newey-West standard errors are used in the cases of serial correlation problem. We specify lag-lengths when applying estimation with Newey-West standard errors according to our findings reported in Table 3.2. The results are presented in Table 3.4.

Next, we account for price-induced energy efficiency improvement by estimating the unrestricted version of Equation (3.14). In estimating this model, an important point to consider is that forecast oil price measures business' expectation of energy price only to a certain degree of precision. Existence of such measurement errors implies that the consistency of the parameter estimates requires the use of Instrumental Variables techniques. We apply the Three Stage Least Squares (3SLS) method, employing the same iterative algorithm used in the first estimation. [16]

[15]This test is for the traditional model and we assume the same conclusion holds for the model with model that includes the expected price.

[16]In choosing instruments, we considered factors related to world energy demand and

Table 3.2: Diagnostic Tests for the Traditional Specification

	Serial Correlation Tests (Ho: No Serial Correlation up to lag #)						Heteroskedasticity Tests (Ho:Homskedastic)	
	Lag #	1	2	3	4	5	Prob. > F(4, 27)	Remark
	Durbin's Alt. Test: Prob. >F	0.12	0.30	0.32	0.41	0.51		
Food (311)	B - G Test : Prob. > F	0.10	0.25	26.00	0.33	0.40	0.88	
	B - G Test : Prob. > F	0.71	0.89	0.38	0.47	0.47		
Beverages and Tobacco (31A)	B - G Test : Prob. > F	0.67	0.85	0.28	0.34	0.33	0.97	
	Durbin's Alt. Test: Prob. >F	0.17	0.38	0.52	0.45	0.55		
Pulp and Paper (322)	B - G Test : Prob. > F	0.13	0.30	0.40	0.33	0.40	0.00	Heteroskedastic
	Durbin's Alt. Test: Prob. >F	0.73	0.57	0.57	0.33	0.43		
Petroleum refining(324)	B - G Test : Prob. > F	0.69	0.48	0.45	0.24	0.30	0.97	
	Durbin's Alt. Test: Prob. >F	0.47	0.32	0.44	0.60	0.36		
Cement Industries (325)	B - G Test : Prob. > F	0.41	0.23	0.33	0.46	0.25	0.04	Heteroskedastic
	Durbin's Alt. Test: Prob. >F	0.47	0.32	0.44	0.60	0.36		
Primary Metal (331)	B - G Test : Prob. > F	0.16	0.35	0.45	0.31	0.42	0.03	Heteroskedastic
	Durbin's Alt. Test: Prob. >F	0.30	0.39	0.61	0.10	0.04		
Fabricated Metal (332)	B - G Test : Prob. > F	0.26	0.33	0.52	0.10	0.06	0.10	
	Durbin's Alt. Test: Prob. >F	0.21	0.43	0.57	0.42	0.58		
Machinery (333)	B - G Test : Prob. > F	0.82	0.96	0.32	0.34	0.33	0.64	
	Durbin's Alt. Test: Prob. >F	0.06	0.17	0.13	0.11	0.20		
Computer and Electronic Products (334)	B - G Test : Prob. > F	0.05	0.14	0.18	0.11	0.18	0.26	First order serial correlation
	Durbin's Alt. Test: Prob. >F	0.02	0.04	0.08	0.11	0.14		Serial correlation of higher order Prob. values for lag#9 & lag# 10 are 0.08 and 0.1, respectively.
Transport Equipment (336)	B - G Test : Prob. > F	0.01	0.01	0.03	0.05	0.06	0.19	
	Durbin's Alt. Test: Prob. >F	0.54	0.44	0.63	0.47	0.45		
Aggregate Manufacturing	B - G Test : Prob. > F	0.13	0.23	0.23	0.22	0.32	0.12	

Notes: All equations are estimated using ordinary least-square, excluding expected prices from equation 3.12. B - G Test stands for Breusch-Godfrey Test; Durbin's Alt. stands for Durbin's Alternative Test conducted after regression with standard errors that are robust to heteroskedasticity. Null hypothesis is rejected for probability values below 0.1. One period lags of the dependent variables are included on the right hand side in all regressions as per equation 3.12. Heteroskedasticity test is based on the Breusch-Pagan Test.

We conduct diagnostic checks once again after including expected prices in the models of the sub-sectors that are included in Table 3.2. Because serial correlation and heteroskedasticity tests are not supported in instrumental variable regressions, we use ordinary least square method to shed some light. We detected heteroskedasticity only in Pulp and Paper. We find the presence of higher order serial correlations in Computer and Electronic Products (up to lag#6) and Transport Equipment (up to lag#3) (Table 3.3). Our results for serial correlation is identical with the previous results at least in terms of which particular cases are characterized by the problem.

Owing to these test results, our estimation strategy is to use the three stage least square (iterative) for a system of the set of equations for which we could not detect existence of heteroskedasticity or serial correlation. We use single equation GMM techniques for the three remaining cases, using standard errors and weighting matrices adjusted for heteroskedasticity and serial correlation by the Newey-West method. The chosen specification for each group is the one that minimizes the GMM criterion according to the test of over identifying restriction (Jensen's J - Test).

3.5 Estimation Results and Analysis

The results reflect the variation in the energy intensity of the sectors as illustrated in Figure 3.6, mainly the uniqueness of the Petroleum and Coal Products and Computer and Electronic Products sectors. Our estimates from the traditional model (Table 3.4) indicate energy using-technical change in Petroleum and Coal Products in line with the upward trend in energy intensity. For the Computer and Electronic Products sub sector, our estimates indicate a possibly very high rate of energy efficiency improvements, in line with a steep decline in the energy intensity observed

supply as well as domestic factors related to business decision processes and indicators of the business environment. We use trends in world oil production and world per-capita GDP to reflect the supply and demand factors. In addition to these global variables, we use lending interest rates, the US-Canada exchange rate, and the TSX composite equity index as indicators of the domestic business environment. These domestic factors are particularly relevant as they can greatly influence business' expectations and decisions. World per-capita GDP and interest rate are from the World Bank, world development indicators; TSX index is from Data Stream; the US- Canada Exchange rate is the official exchange rate from IMF financial statistics yearbook; and world oil production is obtained from the EIA.

Table 3.3: Diagnostic Tests for the Traditional Specification

	Serial Correlation Tests (Ho: No Serial Correlation up to lag #)						Heteroskedasticity Tests (Ho:Homskedastic)	
	Lag #	1	2	3	4	5	Prob. > F(6, 25)	Remark
	Durbin's Alt. Test: Prob. >F	0.41	0.63	0.64	0.78	0.89		
Food (311)	B - G Test : Prob. > F	0.90	0.64	0.78	0.61	0.49	0.55	
	B - G Test : Prob. > F	0.71	0.89	0.38	0.47	0.48		
Beverages and Tobacco (31A)	B - G Test : Prob. > F	0.67	0.85	0.28	0.35	0.33	0.86	
	Durbin's Alt. Test: Prob. >F	0.71	0.89	0.38	0.47	0.47		
Pulp and Paper (322)	B - G Test : Prob. > F	0.13	0.30	0.40	0.33	0.40	0.00	Heteroskedastic
	Durbin's Alt. Test: Prob. >F	0.72	0.57	0.57	0.33	0.43		
Petroleum refining(324)	B - G Test : Prob. > F	0.69	0.48	0.45	0.23	0.30	0.51	
	Durbin's Alt. Test: Prob. >F	0.41	0.24	0.33	0.46	0.45		
Cement Industries (325)	B - G Test : Prob. > F	0.72	0.57	0.57	0.33	0.43	0.36	
	Durbin's Alt. Test: Prob. >F	0.22	0.44	0.57	0.43	0.58		
Primary Metal (331)	B - G Test : Prob. > F	0.16	0.34	0.45	0.31	0.43	0.17	
	Durbin's Alt. Test: Prob. >F	0.11	0.16	0.31	0.20	0.32		
Fabricated Metal (332)	B - G Test : Prob. > F	0.21	0.44	0.57	0.43	0.58	0.22	
	Durbin's Alt. Test: Prob. >F	0.84	0.97	0.43	0.47	0.47		
Machinery (333)	B - G Test : Prob. > F	0.84	0.97	0.43	0.47	0.47	0.80	
	Durbin's Alt. Test: Prob. >F	0.06	0.18	0.13	0.10	0.17		Serial correlation of
Computer and Electronic Products (334)	B - G Test : Prob. > F	0.05	0.13	0.01	0.08	0.13	0.52	higher order (lag#6)
	Durbin's Alt. Test: Prob. >F	0.02	0.04	0.09	0.17	0.23		Serial correlation of
Transport Equipment (336)	B - G Test : Prob. > F	0.01	0.03	0.07	0.13	0.17	0.17	higher order (lag#3)
	Durbin's Alt. Test: Prob. >F	0.64	0.44	0.65	0.69	0.61		
Aggregate Manufacturing	B - G Test : Prob. > F	0.59	0.35	0.54	0.55	0.45	0.12	

Notes: B - G Test stands for Breusch-Godfrey Test; Durbin's Alt. stands for Durbin's Alternative Test conducted after regression with standard errors that are robust to heteroskedasticity. Null hypothesis is rejected for probability values below 0.1. One period lags of the dependent variables are included on the right hand side in all regressions as per equation 3.12. Heteroskedasticity test is based on the Breusch-Pagan Test.

in Figure 3.6. We do not detect energy-using or energy-saving technical change in the Primary Metal sub-sector. There is evidence of energy-saving technical change (energy efficiency improvement) in Food, Beverages and Tobacco, Pulp and Paper, Cement, Fabricated Metal, Machinery, Computer and Electronic Products, Transport Equipment, and overall Manufacturing. The coefficient value is either -0.01 or -0.02 in most cases, including the estimate for the overall manufacturing sector. [17]

The estimates from the price-induced model which captures both the autonomous and price-induced energy efficiency improvements indicates that the traditional model may not fully account for energy efficiency improvements. This can best be judged by noting that the coefficient estimates for the time trend are quite similar across the two specifications. In the Primary Metal sub-sector, where no energy-related technical change was detected, there is no evidence of price-induced energy efficiency improvements as well. The other sub-sectors with no evidence of price-induced efficiency improvements are Beverages and Tobacco, Fabricated Metal, and Machinery sub-sectors.[18] As before, there is energy-using autonomous technical change in Petroleum and Coal sub sector. However, price-induced change is energy saving. We identify price-induced energy efficiency improvements in all groups except for the Computers and Electronics manufacturing and Primary Metals manufacturing sub-sectors.

Explaining sectoral variations

Our empirical results clearly show that there are important variations across Canadian manufacturing sub-sectors. Hence, generalizing the evidence observed at a more aggregate level to specific industries could be misleading. This is important particularly from the perspective of climate policy modeling. To illustrate, consider two particular cases - Computer and Electronics Manufacturing, and the Primary Metal manufacturing sub-

[17] As a side note, we observe that energy and capital are complementaries in all cases except for Computer and Electronics where the relative capital price has no effect. This is consistent with the putty-clay and vintage capital theories of energy utilization in production. Although energy and labour are complementary in the overall Manufacturing, there is variation across the sub-sectors. We find that they are substitutes in Food, Beverages and Tobacco, and Primary Metal.

[18] As before, we observe that capital and energy are complementaries in most cases, the only difference from our previous result is that relative capital price is now statistically insignificant in the Machinery sub sector. We observe much variation in the estimated coefficients of labour price across the two specifications.

Table 3.4: Estimated Coefficients for Traditional Specification with Time Trend.

Industry group	$(PK/PE)^{0.5}$	$(PL/PE)^{0.5}$	Time trend	Lagged EI	Constnat	R^2	F -Stat	P>F	Average Annual Efficiency Change
Food (311)	0.912***	-2.117***	-0.019***	0.241***	2.544	0.95	228.72	0.00	-0.02
Beverages and Tobacco (312)	1.053***	-0.760***	-0.029***	0.202**	1.377	0.84	46.56	0.00	-0.04
Pulp, paper, and paperboards mills; and converted paper products (322)	0.956***	0.961***	-0.017***	0.019	-0.275	0.86	57.09	0.00	-0.02
Petroleum and coal products manufacturing (324)	0.732***	0.024	0.008***	0.147**	-0.198	0.82	181.31	0.00	0.01
Cement and Misc. non-metalic (327)	0.810***	0.715***	-0.035***	0.428***	0.099	0.79	56.27	0.00	-0.06
Primary Metal (331)	0.336***	-0.146	-0.001***	0.565***	0.335	0.97	306.59	0.00	-0.01
Machinery (333)	-0.456***	1.526***	-0.004	0.404***	-0.231	0.89	80.06	0.00	0.00
Computer and Electronic Productt (334)	3.567***	5.304	-0.276*	0.578***	-8.429	0.84	58.22	0.00	-0.65
Transport Equipment. (336)	0.324***	0.728***	-0.017***	0.154***	0.368	0.91	116.08	0.00	-0.02
Aggregate Manufacturing	0.520***	0.418***	-0.016***	0.496***	-0.05	0.93	107.02	0.00	-0.03

Note: *** Indicates significance at 1%; ** indicates significance at 5%; * indicates significance at 10%; and insignificant otherwise.

Table 3.5: Estimated Coefficients for Price-Induced Energy Efficiency Improvement Model

Industry group	$(PK/PE)^{0.5}$	$(PL/PE)^{0.5}$	Expected Price	Lagged Expected Price	Time trend	Lagged EI	Constnat	R^2	F-Stat	P>F	Final GMM Criterion	P-Value for Hansen's J Test $(P>J_{\#})$	Long-Run Elasticity with respect to Expected Price
Food (311)	1.18***	-.45	-0.1	-0.31**	-0.01***	0.44***	0.68	0.88	50.9	0.0			-0.36
Beverages and Tobacco (312)	0.69**	0.32	0.25		-0.02 ***	0.37***	0.91	0.88	54.1	0.0			
Pulp, and paper (322)	0.56***	-0.61	-0.62**		-0.03***	0.25**	2.20				0.14	0.11	-0.55
Petroleum and coal (324)	0.64***	-0.18	0.59**	-0.62**	0.01***	0.10	0.02	0.84	39.5	0.0			-0.02
Cement and Misc. non-metalic (327)	1.13***	-1.02**	0.28	-0.85***	-0.03***	0.57***	1.78	0.98	385.7	0.0			-0.99
Primary Metal (331)	0.38***	-2.52***	-0.26		0.005^	0.44***	2.90	0.94	107.4	0.0			
Fabricated Metal (332)	0.58***	0.13	-0.43***		-0.01***	0.35***	0.57	0.96	176.0	0.0			-0.51
Machinery (333)	0.07	-0.07	-0.28		-0.01**	0.48***	0.23	0.78	37.5	0.0			
Computer and Electronic Product(334)	-0.003	75.94***	13.30	-5.78	-0.67***	0.42***	-63.40				0.02	0.37	
Transport Equipment (336)	0.58***	1.03**	0.18	-0.29*	-0.02***	-0.05	0.25				0.10	0.22	-0.20
Aggregate Manufacturing	0.81***	1.64 ***	0.47**	-0.52**	-0.01***	0.30***	-1.35	0.96	201.2	0.0			-0.04

Note: *** Indicates significance at 1%, ** indicates signifigance at 5%; * indicates significance at 10% and insignificant otherwise.

sectors. The evidence for the Computers and Electronic Products manufacturing sub sector can at least be partly explained in terms of a significant effect of learning-by-doing shown by the highest autonomous energy efficiency improvements. We assert that the coefficient of the time trend captures learning-by-doing, to a large extent. The results for Primary Metal Manufacturing, a sub sector where we do not have evidence for energy efficiency improvements of any type, can be viewed within the context of the results reported in Popp (2001) which shows that energy intensity is not elastic with respect to innovations in the aluminum, metal coating, rolling and casting, and steel foundries. These fall in the primary metal manufacturing sector according to our grouping.

We found energy-using autonomous technical change in Petroleum and Coal Mining along with price-induced energy efficiency improvements. For the Petroleum and Coal Mining, the energy-using autonomous technical change can be attributed to the changing mix of oil produced, particularly the increased share of oil sands processing and bitumen upgrading. For example, Natural Resources Canada (2006) projects that energy intensity in the refining sector will increase by about 20 percent by 2020, as the mix of crude oil for Canadian refineries becomes heavier, hence requiring more processing. However, the sector is also innovating in response to high energy costs. This price-induced efficiency would not be observed if only a traditional model is considered.

Evidence of Price-Induced Energy Efficiency Improvement

We find evidence for price-induced energy efficiency improvements in many of the sub-sectors. The estimated long-run elasticity of energy intensity with respect to forecast oil price is about -0.04 for the overall manufacturing sector, after controlling for substitution effects and autonomous energy efficiency improvement effects. The elasticities range between -0.02 to -0.99. The median estimate is -0.36.

To compare these results to other studies, Linn (2008) predicts that a 10% increase in energy price induces an energy efficiency improvement of about 1%. On the other hand, Sue Wing (2008) finds significant price-induced energy efficiency improvements in only 4 of the 35 industries analyzed, of which two of the 4 are manufacturing industries. Sue Wing also reports cases in which the estimated elasticities imply increase in energy intensity caused by energy price shocks. Because the results did not include the overall industries as a group, it is difficult to establish the estimated coefficients for all industries from Sue Wing's results. However, Sue Wing aggregates each component of the changes in industry-specific energy intensities to the aggregate economy and concludes that induced innovation led to a 9% decline in energy intensity compared to the base year. Moreover, Sue Wing shows that, whether it is induced or autonomous, technical change was energy-using until 1980 and is energy-saving thereafter.

Popp (2001) estimates the effect of energy price on energy use by considering both direct and indirect effects. The indirect effect is captured by considering that energy use is affected by the knowledge stock which is itself driven by energy prices. The indirect effect leads to induced energy efficiency improvements. The breakdown of the elasticities of energy price is computed by using a one period lag in energy price changes on the level of energy knowledge. Popp estimated the relationship separately for 13 industries. By using the empirical results from Popp (2002) which show that there is a positive relationship between energy price and patents (that are used to construct energy knowledge stock) used in the estimation of energy intensity, the effect of energy price via induced innovation is computed. The median elasticity of energy use with respect to energy price via induced innovation is -0.372, which is very close to our result.

3.6 Conclusion

We have estimated the relationship between energy intensity and expected energy price controlling for capital and labour prices relative to the actual energy price to account for substitution effect and the time trend to account for autonomous energy efficiency improvement. Our results indicate the existence of price-induced energy efficiency improvements , beyond the substitution effect, and autonomous energy efficiency improvements. Variations across the sub-groups suggest that technical change may not be induced by energy prices in some cases and may rather be autonomous, or entirely price-dependent. Moreover, there are cases where there is no evidence of technical change improving energy efficiency (e.g., primary metal manufacturing sector).

Our study is different from the previous literature in three respects. First, we provide the first such study utilizing Canadian manufacturing sector data. Second, we emphasize that energy price induces a host of various activities all of which contribute to energy efficiency improvement. Thus, focusing on a particular indicator of technical change (whether it is innovation– R&D, or adoption of new technologies) might result in estimates that wrongly attribute the unaccounted indicator of technical change to the substitution effect. Third, we note that estimation of price-induced efficiency improvement has been constrained by the impossibility of separating substitution and efficiency-improvement effects when only using actual price data. We underline that actual energy price is, in the first place, relevant to modeling energy efficiency-improvements only to the extent that it is a good proxy for the forecast price. We observed that it is in fact not a good proxy for forecast comparing to forecasts that were released by the the EIA (energy information administration). We exploited this divergence to include two price variables in our models as two distinct variables to capture the two distinct price effects.

We find that the coefficient estimates for autonomous technical change does not change much across the two specifications (with and without the inclusion of forecasted prices) while the substitution effects (price elasticities) varied more significantly (Tables 3.4 and 3.5). The most important implication of our results is that price-induced energy efficiency improvements and autonomous energy efficiency improvements both contribute to changes in the trends in energy intensity of Canadian manufacturing.

These results can be used in energy-economy models of climate policy analysis. Until recently, such economic models treated the energy efficiency improvements (EEI) as price-independent or autonomous (AEEI). It is only recently that economic models of climate policy analysis have started to introduce various ways of incorporating endogeneity of technical change. Estimates for the parameter values to be used to formulate these relationships are, however, still not well developed. Our results can be of significant use in this respect.

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Chapter 4

"The Shale Gas Revolution": An Opportunity or a Challenge to Alberta's CO2 Abatements?

4.1 Introduction

Alberta's economy is heavily dependent on the development and use of energy resources that are also a major source of greenhouse gas (GHG) emissions. Therefore, global environmental demands to reduce greenhouse gas emissions have very strong, and usually negative, implications for the long-term growth and viability of Alberta's resource based economy.

Alberta's current GHG abatement policy reflects Alberta's attempt to reconcile growing domestic and global environmental demands while ensuring the long-term viability of its important energy sector. In order to achieve these seemingly disparate objectives, Alberta's environmental policy is geared toward an end-of-pipe, carbon capture and storage (CCS) policy. This means businesses can produce emissions consistent with a pro-growth strategy and CCS technologies will be relied upon to handle the resulting emissions.

In this paper, we critically evaluate the long-term viability of CCS technologies within the context of the shale gas revolution. Natural gas prices have been declining over the last 5 years mainly due to the shale gas revolution particularly in the United States. During the same period, gross natural gas production has been increasing in the United States even while production declined in Canada and the rest of the world in 2009. Since 2000, shale gas production has increased from accounting for only 1% of

US production to 20% in 2009 (Stevens, 2010).

This revolution has arisen because technological innovations have made the extraction of large supplies of shale gas economically viable. The 2010 annual energy outlook of the Energy Information Administration (Energy Information Administration, 2010) predicts that shale gas output could increase to 8 trillion cubic feet (tcf) per day by 2025 and 10 tcf by 2035. In Canada, the National Energy Board (NEB) reports that, as of July 2009, 234 horizontal wells were producing Shale Gas from the Montney shale, raising output from zero in 2005 to 376 million cubic feet per day; 8 million cubic feet per day is being extracted from the Horn river basin; and 0.15 million cubic feet per day by the Horton Bluff Group in New Brunswick. Additional projects are being undertaken in southern Alberta and Saskatchewan by the Colorado group and in Quebec, by the Utica group. The outlook has, therefore, has bee one where shale gas could allow Canada to meet its own need for natural gas well into the 21st century (National Energy Board, 2009).

We argue below that lower gas prices resulting from the expansion in shale gas production now necessitate a public subsidy for CCS adoption, larger than many would be able to ethically defend. We also show that, even with large public subsidies for CCS adoption, Alberta's emission reduction objectives would not be met.

We then contrast Alberta's current CCS policy with other options available to the government. For example, we show that a carbon tax would achieve Alberta's emission targets after a relatively short adjustment period, but the tax will necessarily impact negatively on specific energy sources.

As a point of comparison, we examine the response from a command and control policy that mandates zero dirty coal-fired generation after 2020.[1] Interestingly, this policy can create a niche for the natural, unsubsidized adoption of CCS technologies, but only before the shale gas revolution. After the drop in natural gas prices, this niche is completely occupied by natural gas fired generation facilities.

[1] That is, coal is allowed only if coal-fired plants are equipped with CCS. This is similar to assuming that the Federal government would go ahead with enacting the regulation governing coal electricity, announced on June 23, 2010 (http://www.ec.gc.ca/default.asp?lang=En&n=714D9AAE-1&news=E5B59675-BE60-4759-8FC3-D3513EAA841C).

The most important policy implication from the shale gas revolution, however, is the important role to be played by natural gas fired electricity generation. Our analysis shows that dirty coal is replaced by natural gas fired generation units rather than by coal fired generation units equipped with CCS technologies, as envisioned in Alberta's environmental policy. Even when CCS is subsidized to promote its use, the lower gas prices are sufficient to drive most of the CCS coal and dirty coal from the market place. The one clear theme emerging from this paper is that the shale gas revolution has undermined any long-term case for subsidized CCS adoption in Alberta.

The rest of the paper is organized as follows. In the second section, we briefly discuss related literature followed by an overview of the current GHG emission reduction approach in Alberta. The CIMS model, the baseline input data, and natural gas price scenarios are discussed in section 4. We present the analysis of our results in section 5 and present conclusions in section 6.

4.2 Related Literature

Our paper is related to three distinct strands of literature. The first is a small body of specialized literature dealing with environmental policy in Alberta. As in MKJA (2007), our paper uses the Canadian Integrated Modeling System (CIMS) to comment on Alberta's environmental policy, but can be distinguished from MKJA by the fact that their analysis is carried out based on assumptions that were applicable before the shale gas revolution. Our paper is the first to examine the implications of the shale gas revolution for GHG abatement policy in Alberta. Brown and Krupnick (2010) provide analysis of the implications of shale gas revolution in the context of the US economy. Recent study by Cleland (2011) provides analysis of the overall implications of the shale gas revolution in the context of Canada but not specifically explaining the implications for GHG mitigation strategy. Among the main policy recommendations of the study, we find the recommendation to 'avoid trying to pick winners and use performance measures in preference to specified technologies when designing programs or regulations' very relevant to the issue we are analyzing in this study. A related point is the need to approach CO2 abatement through pricing rather than regulation.

The second strand of literature examines the role of learning by doing. One important reason for subsidizing CCS adoption is to promote any cost savings that can be gleaned from learning by doing. This may be one reason why the Alberta government has been keen to subsidize demonstration projects (Alberta Carbon Capture and Storage Development Council, 2009). Our paper is related to the empirical evidence showing that technology diffusion follows an S-shaped logistic curve with three characteristic phases: initially, market penetration is slow as demonstration projects are undertaken; followed by a rapid increase in market share during commercialization phases; and eventually, growth slows down as technology matures (Stoneman, 2002)). Over time, costs may decline via learning by doing, learning by using, economies of scale in production; and research and development (R&D) by producers/suppliers (McDonald and Schrattenholzer, 2002). Learning is, therefore, a positive externality flowing from the early adopters. This justifies a public subsidy for early adoption. We argue in our paper that the learning rates necessary to make CCS adoption viable are too high and imply too large a subsidy when compared to other available policy options.

Public subsidy for CCS demonstration projects can be viewed in the context of the market failure theory. More generally, Jaffe et al (2004) and Jaffe et al. (2005) argue that the interaction of market failures associated with pollution and the environment, and market failures associated with the development and diffusion of new technology suggest a strong case for public policy to foster development and diffusion of technologies. Providing insurance against risks constitutes another form of subsidy (Dybvig and Spatt, 1983). Thus, insuring against liabilities from possible leakage from the sink after the project's life plays a role of addressing public concerns as well as reducing uncertainty that might deter CCS adoption.

The third literature of importance focuses on performance versus technological standards. In terms of which policy instrument is better suited to induce development and diffusion of abatement technologies, Jung et al. (1996) show that performance standards (technology standards) are ranked the lowest. Moreover, Fischer (2008) argues that technology policy is more effective with fuller emissions pricing and is better viewed as a complement to, as opposed to a substitute for, emission mitigation policy.

Empirically, very useful insights can be drawn from the US experience with Sulfur Dioxide (SO2) control in the electricity sector. This provides a very good learning case as it possesses a number of similarities with the Alberta CCS strategy. In particular, the 1978 amendment to the National Ambient Air Quality Standards (NAAQS), mainly motivated by the protection of the miners of high sulfur content coal, is very relevant. The amendment effectively required installation of flue gas desulfurization equipment (scrubbers) in new coal fired power plants (Ackerman and Hassler, 1981; Gollop and Roberts, 1985; Gollop and Roberts, 1983). The US States in which dirty coal mines were located provided varying levels of financial assistance to power plants in order of help to finance adoption of scrubbers (Carlson et al., 2000).

We can draw some important lessons from this experience. First, we note that the move to an across-the-board scrubber-forcing regime was largely driven by lobby groups composed not only of environmental groups but also of the dirty coal producers; known as the “Dirty Coal/Clean Air Coalition” (Ackerman and Hassler, 1981; 1980). Effectively, the dirty coal miners lobbied for scrubber subsidies for power plants in their area so that local coal would be used and environmental standards met. In Alberta, it appears that the oil and gas industry is supporting CCS policy. Views expressed by an industry group known as ico2n (`www.ico2n.org.`) lauding the Alberta CCS Development Council’s recommendation for continuous government CCS subsidy is a case in point.[2] The results of our analysis are consistent with those found in Ackerman and Hassler (1980; 1981) and provide a new example of how the imposition of technology standards is suboptimal. This analysis supports the statement by Cleland (2011) which reminds policy makers to stick to the basic idea that market works and we should be cautious about calls from interest groups for governments to somehow fix things.

One of the problems with technology-forcing policies is that there is no guarantee that they will lead to the desired levels of emission reductions. In the case of CCS, there is no guarantee that installation of CCS would result in the emission reductions implied by the maximum capture efficiency. Hence, requiring firms to install CCS may not necessarily be equivalent to requiring emission cuts, thereby relieving the firms from tangible environ-

[2] `http://www.ico2n.com/wp-content/uploads/2010/07/Alberta-got-it-right.pdf`

mental constraints. This is particularly important if CCS adopting firms will continue to receive public subsidies which implies that the firms are not generally being held accountable for anything. The Alberta Carbon Capture and Storage Development Council, (2009) report calls for continuous support at least in the medium term.

A second, and most important, problem is that even if the maximum capture rate is actually achieved, this does not necessarily mean that the technology used provides the least-cost way to achieve the abatement targets. Evaluating the US experience, Gollop adn Roberts (1985), for example, show that the move to technology-based emission standards has raised the cost of achieving the target SO2 emission rate by about 47%. In the same vein, Carlson et al. (2000) report that the 1990 amendment to the clean air act introducing a universal cap and trade scheme could in the long run result in \$700–\$800 million per year in cost saving compared to a command-and-control program characterized by a uniform emission rate standard to be achieved by adopting scrubbers.

Deployment of CCS depends on its costs competitiveness with alternative abatement technologies (Johnson and Keith, 2004). Because of this, its high investment costs have significant negative effects on CCS deployments. Lohwasser and Madlener (2009), for example, show that the share of CCS in electricity sector in Europe could be about 16% in 2025 assuming the lowest possible cost estimates. This percentage would be only 2% if the highest investment cost was applicable. In the electricity sector, market penetration of CCS also depends on market competitiveness of electricity generated by plants equipped with CCS. Thus, the true cost competitiveness of CCS is best measured by comparing it with its closest marginal competitor which can only be determined in the context (Anderson and Newell, 2008). In this respect, fuel prices can have important effects because they can alter the reference technologies against which the competitiveness of CCS will be measured. In a cost analysis provided by David and Herzog (2000), for example, there is a significant difference between reference technologies when natural gas prices are assumed to be \$3/MBtu and \$6/MBtu, respectively. The reference plant is a coal-fired plant when natural gas price is \$6/MBtu while it is a natural gas fired plant when it is \$3/MBtu. This suggests that fuel price dynamics play an important role in determining CCS competitiveness and hence its market penetration.

The "shale gas revolution" in North America that has led to a doubling of natural gas supply and significant drops in price, has, therefore, an important role to play in determining the prospects of CCS deployments. Cheaper supplies of natural gas imply substitution away from coal-fired power generation, thereby changing the marginal competitor of coal-fired plants with CCS to natural gas-fired power plants. Experience shows that capture costs per tonne of CO2 are lower for coal-fired processes than for gas-fired processes (Gielen and Podlanski, 2004). Apart from creating cost disadvantages to CCS, natural gas can also deter investment in CCS because natural gas has a low CO2 content and hence the resulting GHG emission reduction may mean that the very reason why CCS is required may not exist anymore unless the emission reduction targets are extremely high.

4.3 The Current Policy Environment

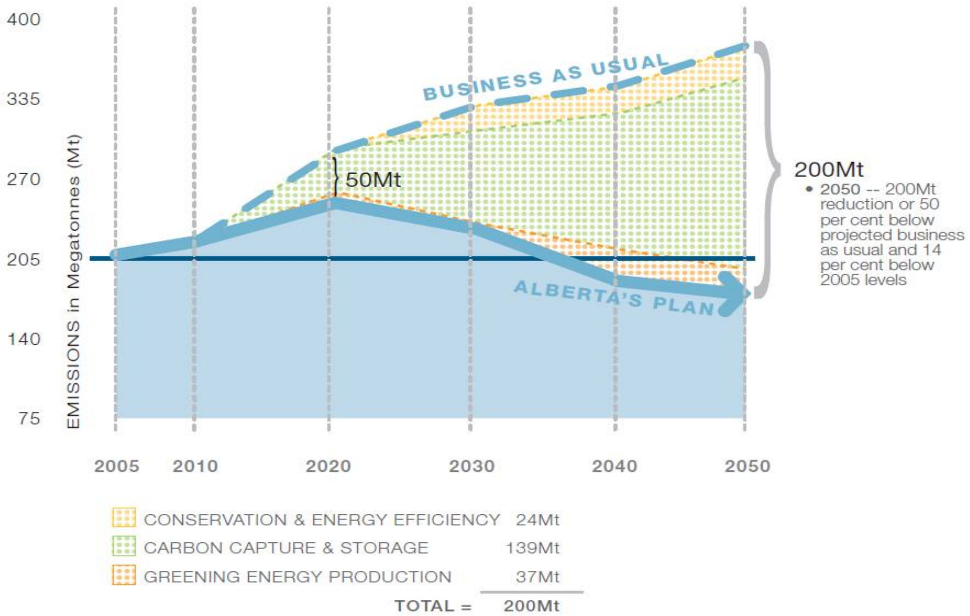
4.3.1 Policy Objectives

Alberta's climate change action plan (Government of Alberta, 2008) lays out emission reduction goals of 200 Mt/year relative to the business as usual forecast by 2050. This is about 14% below 2005 levels. As shown in Figure 4.1, which is taken from the Government of Alberta document, CCS technologies are shown to have the potential to account for over 70% (139 Mt/year) of the outlined emission reductions goals by 2050.

The business as usual forecast in Figure 4.1 incorporates the existing regulatory framework known as the specified gas emitters regulation that has been in effect since July 1, 2007. This regulation requires that large emitters (facilities with 100,000 tonnes of GHG or more a year) reduce emissions intensity by 12 percent per year relative to approved baseline emissions intensity.[3] The GHG emission reduction goals laid out in the

[3] That is, targets are set at the facility based on baseline levels and that facility's performance over time is compared against its approved baseline emissions intensity based on the average intensities during 2003 to 2005 (Government of Alberta, 2007). Independent third party verification of a facility's baseline and annual emission intensity is a mandatory requirement. The framework allows firms to meet compliance requirements by purchasing Alberta-based offset credits, contributing to the Climate Change and Emissions Management Fund at a rate of $15 t/CO2e, or by changing their operations (energy efficiency and fuel substitution

Figure 4.1: Alberta Emission Reduction Plan



action plan, therefore, indicate the desire to reduce GHG emissions beyond what could be achieved under the existing regulatory framework.

Based on these goals, the government has adopted ensuring CCS deployments as a key policy objective. It is important to note that the forecasts of emission reduction trajectories and the the possible contributions of alternative reduction mechanisms (reduction wedges) were generated under the assumption of a carbon tax regime of \$50/t CO2e during 2011 - 2015; \$75/t CO2e during 2016 - 2020; \$100 /t CO2e during 2021 - 2025; \$150/t CO2e during 2026 - 2030; and \$200/t CO2 during 2031 - 2050 (MKJA, 2007). This indicates that the government would have to price GHG emissions to achieve CCS deployment of the magnitude laid out in the action plan. The existing approach is, however, to subsidize demonstration projects in order to achieve deployment of commercial scale CCS operations by 2015. More specifically, the policy objective is to implement the three key immediate actions prescribed by the ecoEnergy Carbon Capture and Storage Task Force (2008).

The first immediate action prescribed by the Task Force was for Federal and Provincial governments to provide new public funding amounting to \$2 billion to leverage industry investment in the first three to five CCS projects. This action was recommended in order to achieve GHG emission reductions of about 5Mt/year through an initial wave of industrial CCS installations. The second recommended immediate action calls for regulatory clarity regarding the strategy of assuring that the provincial governments are responsible for long-term liability obligations associated with CCS storage. The third immediate action pertains to the creation of CCS-specific measurement and crediting protocols with the objective of ensuring that any CO2 credits from CCS are no less tradable or valuable than other credits.

Beyond these immediate actions, the Task Force also makes a case for continuous public support to sustain CCS activities through an interim stage until the carbon market has matured or until other regulatory machinery is at the point where the financial gap facing CCS is sufficiently closed (ecoEnergy Carbon Capture and Storage Task Force, 2008).

The Government of Alberta responded by announcing the establishment of a CCS technology fund amounting to $2 billion, later ratified through the Carbon Capture and Storage Funding Act (Government of Alberta, 2009), in order to begin CCS implementation in Alberta. It also commissioned a multi-disciplinary CCS Development Council (building on the work of the ecoENERGY CCS Task Force) as a public-private partnership, mandated with the tasks of assessing and recommending appropriate timelines, policy and regulatory requirements for CCS standards. Specifically, the Council was mandated with the task of coming up with recommendations regarding regulatory requirements for ensuring that new large industrial facilities are designed and built to enable the capture of CO2; and ensuring that existing large industrial facilities have plans in place to be capture-ready; developing a policy approach and securing the necessary financial resources required to build the CO2 infrastructure; and examining and proposing a suite of tools and incentives to ensure industries in Alberta maintain leadership roles in implementing CCS technology.

4.3.2 Implementing CCS Adoption in Alberta

The Alberta CCS Development Council released its final report, considered to be a blueprint for achieving swift, safe and widespread adoption of carbon capture and storage (CCS) in Alberta, on March 4, 2009 (Alberta Carbon Capture and Storage Development Council, 2009). Specific steps and measures regarding CCS adoption were outlined in terms of what the Council recommends as a mechanism for implementing the actions outlined in ecoEnergy Carbon Capture and Storage Task Force (2008). It was shown that there is a significant financing gap that prohibits the private sector from undertaking CCS investments. The gap exists even after considering the commercial use of the captured CO2 for enhanced oil recovery (EOR) and the avoided compliance costs according to the specified gas emitters regulation. Specifically, it was assumed that captured CO2 could be sold to EOR businesses at a price of $25/t, and adding the avoided $15/t compliance cost, CCS installation could generate $40/t for adopting firms. On the other hand, a CCS cost survey shows that investment cost ranges between $60/t and $250/t. This cost range is $60 to $150 for the electricity sector, resulting in financing gap ranging from $20/t to $110/t.

If the authorities were to use a carbon tax to implement CCS, this calculation suggests that an additional carbon tax of at least $20/t is needed. The Council, however, argues for the public to fill the gap, at least in the short run. The arguments are based on four main points. The first is that the public would gain in terms of additional oil production from EOR leading to increased government revenues. Second, the province would avoid the negative effects of additional taxes on investments in developing its resources, thereby remaining economically competitive. Third, and specific to the electricity sector, the deregulated electricity market would mean that plants incurring CCS investment costs may not be able to compete, in the market, as a result of which, such investments may never take place unless the government subsidizes the incremental capital costs. Fourth, investments in initial demonstration projects could induce widespread deployment of CCS in the future, due to learning effects that are generated. As such, the initial deployments are considered to be demonstration projects and hence implementing a first set of commercial-scale projects will initiate a learning-by-doing phase, which will result in cost reductions due to improved materials and technology design, standardization of applications, system integration and optimization, and economies of scale (ecoEnergy Carbon Capture and Storage Task Force, 2008). Public subsidy is, thus, a reward for early action considering these long term benefits.

More generally, public investment in CCS now would enable the province to meet stringent national or intentional emission reduction requirements in the future without negatively affecting its oil-based economic growth. In line with the ecoEnergy Carbon Capture and Storage Task Force

(2008) call for Federal and provincial governments to provide stable financial incentives to help drive CCS activities beyond the phase-one projects, the Alberta Carbon Capture and Storage Development Council (2009) argues that there is a solid business case for continued government support for CCS.

In addition to making a case for public support, the council also outlines alternative approaches to providing the desired financial support. The council specifically recommends the "pay-for-results" approach - a delivery of financial support to CCS through a standardized dollar-per-tonne-captured payment (Alberta Carbon Capture and Storage Development Council, 2009).

Following the report, Alberta legally enacted the previously announced $2 billion CCS Fund on June 4, 2009.[4] So far, the government has allocated $779 million, of which the federal government contribution is $343 million, to help kick-start a CCS project, known as "project pioneer," a coal-fired power generation equipped with CCS with CO2 capture potential 1Mt per year. Similarly, the two governments promised Shell Energy, for its "Quest project," a total of $865 million, of which $745 million was from the Alberta CCS fund. "Quest" is expected to capture and store 1.2 million tonnes of CO2 annually beginning in 2015 from Shell's Scotford up-grader and expansion. A Letter of Intent to contribute $495 million was also signed with Enhance Energy and North West Upgrading to construct a 240-km carbon dioxide (CO2) pipeline system that will greatly increase the capacity for future carbon capture and storage projects in the province. The three projects are part of the initial plan to achieve 5 Mt per year in emission reductions beginning in 2015, solely through CCS implementation. Of these, only "project pioneer" is in the electric power generation sector.[5]

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[4] Carbon Capture and Storage Funding Act, `http://www.qp.alberta.ca/574.cfm?page=C02P5.cfm&leg_type=Acts&isbncln=9780779742141&display=html`

[5] "The percentage of total CCS related costs supported by the program will be limited to a maximum of up to 75% of total incremental CCS costs; with funds disbursed prior to commencement of operations being limited to a maximum of up to 40% of the total approved funding for the project. A maximum of up to 20% of the total approved funding for the project will be paid on commencement of operations. The remaining percentage of approved funding (at least 40%) will be disbursed as CO2 is captured and disposed, over a maximum of 10 years. The calculation of funds to be disbursed will be based on each project's remaining grant contribution, divided by the expected CO2 capture volumes (defined in the grant agreement) over a ten year period, and will be disbursed as volumes of CO2 stored are confirmed. After all incremental CCS costs, plus a mutually accepted rate of return have been recovered by the proponent, revenue from the sale of emissions credits, CO2 for EOR, and other revenue streams generated by the capture, transport and storage of CO2 will

The Council's report also articulated that should regulate Alberta new oil sands, coal-fired power plants and other manufacturing and processing projects to be capture ready beginning in 2010 to 2015. In this respect, the approvals policy for oil sands projects articulates the requirement for being CCS ready, as of January 17, 2008, for all new in situ bitumen production projects using non-gaseous fossil fuels for steam generation.[6] Such binding restriction is, however, not being imposed on the electricity sector. For example, the Alberta Utilities Board has recently reached an interim decision to grant permission for construction of a traditional coal-fired plant.[7] The Federal Government has, however, announced on June 23, 2010 a new regulation, to be effective by July 1, 2015, that requires power companies to close their coal-fired facilities at 45 years of age or at the end of the power purchase agreement, whichever is later. This implies that companies would be prohibited from making investments to extend the lives of those plants unless emission levels are reduced to the emission levels of natural gas combined cycle plants. The new regulation encourages electric utilities to transition towards lower or non-emitting types of generation such as high-efficiency natural gas, renewable energy, or thermal power with carbon capture and storage (CCS).

A bill mandating the provincial government to assume long-term liability was also enacted (Government of Alberta, 2010) as a step towards implementing the recommendations to assume risks. More recently, two important events have occurred. One is the news release from the Government of Alberta on March 11, 2011 announcing the establishment of an expert panel to Review Alberta's CCS Regulatory Framework and report by Fall 2012.[8] The second news is that Alberta is updating its carbon offset credit program to allow multiple-credits in such a way that CCS projects that are primarily used for straight injection and sequestration could receive additional offset credits compared to capturing for EOR use. Accordingly, large-scale, direct injection CCS projects that meet specific criteria will receive a bonus credit for every tonne of offset credit created through the capture and storage of their CO2.[9]

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reduce allowable costs upon which the grant is based." see www.energy.alberta.ca/Org/pdfs/CCS_FPPInfo.pdf)

[6] http://environment.alberta.ca/documents/OSEMD_Approvals_Program_Policy.pdf

[7] http://m.theglobeandmail.com/globe-investor/news-sources/?date=20110630&archive=ccnm&slug=201106300709745001&service=mobile

[8] http://alberta.ca/home/NewsFrame.cfm?ReleaseID=/acn/201103/30045A5A2059C-B0A9-5866-5BEC35F54255E39A.html

[9] http://alberta.ca/home/NewsFrame.cfm?ReleaseID=/acn/201106/

Clearly, implementing CCS adoption in Alberta is in full swing and the provincial government has so far taken, or announced plans towards taking, all steps recommended by the ecoEnergy Task Force and the Alberta CCS Development Council. The recommendations imply a large public subsidy to finance a wave of 3 to 5 demonstration projects and provision of various incentives providing continuos financial support in the future. Significant amount of public subsidy will have to be provided every year in order to achieve CCS deployment that would permit emission reductions to the tune of the amount outlined in the action plan (Leach, 2011). Such a big commitment of public investment for CCS has raised an important ethical issue related to subsidizing certain forms of energy production.

4.4 Description of CIMS and Baseline Input Data

4.4.1 The CIMS Model

The Canadian Integrated Modeling System (CIMS) is a hybrid energy-economy model developed and operated jointly by the Energy and Materials Research Group (EMRG) at Simon Fraser University and MK Jaccard and Associates. It tracks energy-end use technologies in both energy supply and demand sectors through retirement and replacement, and retrofitting of old stocks (Bataille, 2005).[10] A two-tiered approach is used in driving CIMS simulation results. That is, the energy market (the energy flow model) and the goods market equilibrium (the macroeconomic feed backs) results are solved separately and sequentially, with the energy market equilibrium being determined first. That is, first, the energy supply and demand integration system adjusts energy prices and quantities by iterative convergence between supply and demand for four energy end-use forms – electricity, natural gas, refined petroleum and coal.[11,12] The interactions between demand

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[10] The discount rates used in annualizing the upfront capital costs are individual discount rates so as to take risk and option values into account, and incorporate intangible benefits or costs estimated using stated preference experiments. These steps are taken to render CIMS simulation "behaviourally realistic."

[11] The equilibrium feedbacks incorporate both the convergence in energy demand and supply and macroeconomic feedbacks. This is different from traditional bottom up models that track changes in energy service demand regardless of supply.

[12] The macroeconomic integration is captured through goods and services demand feedbacks via an adjustment factor that makes use of the price elasticities and financial costs of the product (see Bataille, 2005) for a detailed description of how the multi-

and supply determines the equilibrium energy price, which is linked to the economic module through energy price elasticity of the demand for energy in the production sector (Battaille, 2005).[13]

The energy demand module consists of the industrial, residential, commercial and transportation sectors. The energy supply module consists of primary energy supply (petroleum crude extraction, coal mining, and natural gas extraction and transmission) and electricity generation. We focus on the electricity sector in our analysis although we run the simulation in an integrated fashion, taking the dynamics in all sectors into account.

Being a technology-rich model that is based on how the shares of different energy-using equipment change in response to variation in costs, CIMS has obvious benefits for research that targets market penetration of a specific technology, such as CCS. It allows us to track CCS adoption rates over time and under various scenarios. In addition to this benefit, our decision to adopt CIMS is also based on the fact that previous analysis of CCS adoption in Canada, in which context we would like to discuss our results, was undertaken using CIMS. The assessments that form the background information for the Alberta Climate Change Strategy was also based on a study using CIMS(Government of Alberta, 2008).

However, CIMS has one obvious shortcoming - it does not permit changes in production (supply) of goods and services in the economy, including energy production.[14] The effect of any excess demand is absorbed by net exports. In the electricity sector, however, this would raise issues related to transmission capacity, as a result of which the share of net exports were maintained at base year levels. This may have the implication that the projected adoption of new technologies, including CCS, could be somewhat exaggerated for any given scenario because the algorithm does not permit for not generating electricity, it only determines what generation types are adopted, given demand and the total supply (which is fixed). If we predict limited market penetration of CCS in the electricity sector

pliers are derived). Hence, CIMS constitutes three modules - energy service demand, energy supply and macroeconomic.

[13]Although structural changes through demand feedback are permitted, the CIMS algorithm is set in such a way that the maximum possible reduction in demand due to increases in the cost of production emanating from energy price rises can not exceed 50 percent..

[14]This is a problem specific to the version of CIMS that was used have; the latest version of CIMS attempts to overcome this shortcoming.

due to a policy, therefore, it reflects conditions under the most conducive circumstance due to the way the simulation algorithms are solved. This can be viewed as an advantage given that our objective is to evaluate the potential for CCS market penetration in the Electricity sector in Alberta. The disadvantage is that this exaggeration also applies to the penetration rates for renewables and natural gas. Thus, while CIMS is a good choice for comparison with the previous analysis, a full examination of the issues would benefit from a model that is more realistic along this dimension.

The Electricity Sector and CCS Technologies in CIMS

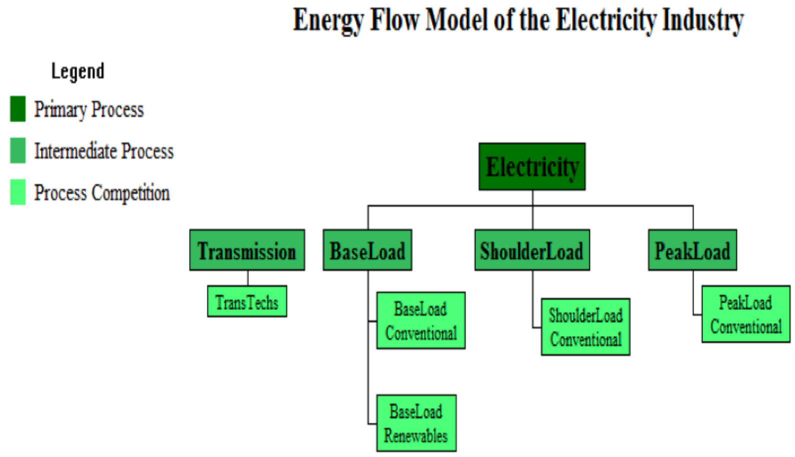
The CIMS technology file consists of existing generation capacity characterized by types, costs, and life. Some of the available power plants may retire during the simulation period, and their replacement is based on market competition according to costs. Hence, an existing coal-fired plant, for example, could be replaced by either a new coal plant (retrofitted) or a natural gas-fired power plant, renewables such as wind and solar power; or, technologies that are available in the future, such as coal and natural gas-fired power plants equipped with CCS. Hence, descriptions of known but not yet adopted technologies are also available.[15]

As shown in Figure 4.2, the technologies in each node compete with each other given the total demand to be supplied according to the market share of each node within each category of power generation. For example, all the renewable technologies compete with each other and even if one particular technology wins all of the market in that node, its total share in overall power supply cannot exceed the share of the particular node.

Table 4.1 shows these node splits. The base-load, shoulder-load, and peak-load are assigned 0.1461, 0.3586, and 0.4953, respectively. As shown in Table 4.1, renewables account for 5% of the base load that itself accounts for 50% of total electricity generation in the base year. Coal-fired power accounts for 72% of total, and 93% of base load electricity generation. Thus, about 97% of power generation in Alberta was based on fossil-fuels, 72%

[15]Technology market shares are determined by: $MS_{it} = \frac{LCC_{it}^{-v}}{\sum_{i=1}^{i=n} LCC_{it}^{-v}}$ where MS_{it} is market share of technology$i$ in time t, LCC_{it} is levelized cost per unit of output for technology i in time t, v is a variance parameter which determines the slope of the logistic curve (takes values greater or equal to 1); and n is the number of technologies competing.

Figure 4.2: A snapshot of CIMS Electricity Sector Energy Flow Model



coal and 25% natural gas. However, natural gas is found only in the peak load or shoulder load categories.[16,17]

Over the forecast period, it is possible to hold base year shares constant or allow them to vary. While there might not be any justifiable reason to allow the node splits between peak load, shoulder load, and base load to vary, the shares of the nodes within these major nodes should be variable. In this way, the total market share of renewables, which was 2% in the base year, should be allowed to vary in order to take the growth potentials of these technologies into account. For example, most of the Alberta's electric power generation capacity increment in 2010 (320MW) came from three new wind power facilities totaling 214 MW (Energy Resources Conservation Board, 2011).[18] The CIMS simulation algorithm permits such flexibility in that it would be possible to let the nodes within each generation type compete. That is, we let the winners in each node compete for

[16]We observe that shoulder-load is simply base-load but with no renewable sources of electricity included.

[17]Note that CIMS electricity sector data deals only with utility electricity. Natural gas dominates industrial cogeneration. In 2010, 69 per cent of the natural gas-fired capacity in the province was classified as cogeneration (Energy Resources Conservation Board, 2011). (`http://www.energy.alberta.ca/OurBusiness/electricity.asp`)). With cogeneration included, coal-fired power plants generated almost 59 per cent of the province's electricity in 2010, while natural gas and hydro accounted for 34 and 2 per cent, respectively. The remaining 5 per cent was generated by wind and other renewable sources (`http://www.ercb.ca/docs/products/STs/st98_current.pdf`). In CIMS, cogeneration associated to steam production is modeled in the specific industries where it takes place.

[18]TransAlta brought on Summerview 2 and Ardenville (66 MW each) and NextEra brought on Ghost Pine Wind Farm (81.6 MW).

Table 4.1: Base year (2000) Market Shares of Electricity Technologies

	Peak Load (0.1461)	Shoulder Load (0.3586)	Base load (0.4953)	Market Shares (%)
Splits				
Conventional	100%	100%	95%	98%
Renewables	0%	0 %	5%	2%
Shares in Base Stock				
Conventional				
Hydro			7%	3%
Combined Cycle Gas	55%	28%		18%
Single Cycle Gas	45%	0		7%
Single Cycle Coal	0	72%	93%	72%
Renewables				
Biomass			40%	1%
Small Biomass			3%	
Micro Turbines off Flare Gas			56%	1%
Wind (good site)	-	-	1%	0.03%

Note: The sum of conventional and renewable market shares in total base stock is not 100 because of rounding.

the demand to be supplied by each category (peak load, shoulder load, or base load).

In addition to these technologies constituting the base year stock, the technology database also includes technologies that are not yet in use, including CCS technologies. Each technology comes as a power generation plant characterized by generation capacity, upfront capital costs, fuel type and the amount of fuel needed for a GJ of electricity generation which determines applicable fuel costs given fuel price assumptions. Also included are the non-fuel operating and maintenance costs, year of availability and retirement (which determines the technology life), discount rates, and assumed technology learning rates and maturity. The fuel type and its use per unit of electricity generated, together with fuel-specific emission intensity, determines emission per unit of electricity generated by each technology type.

Under business-as-usual assumptions, demand for new technologies arises when an existing technology retires or when demand for each power generation type increases. In that situation, the technology with the least cost is deployed. Under any given policy, a carbon tax for example, some technologies may fail to become competitive because costs include any existing subsidy or carbon charge. Thus, a carbon tax achieves its emission reduction objectives by forcing some technologies to retire even though they may not have reached retirement age. In a similar fashion, a policy of phasing out certain types of technologies can also be modeled by simply adjusting years of unavailability.

There are three types of plants with CCS technologies identified in the CIMS technology data base: conventional combined cycle coal with CCS, Integrated Gasification Combined Cycle Coal (IGCC) with CCS, and the Natural Gas Combined Cycle (NGCC) with CCS (Table 4.1). The capture efficiencies assumed are according to the information gleaned from the IPCC comprehensive data presented in Table 4.2 (IPCC, 2005). Table 4.2 shows that representative emission reductions are 85% and 86% for pulverized coal (PC) and IGCC plants with CCS, respectively. Capture energy requirement increases fuel use per unit of electricity generated by 31% for PC and by 19% for IGCC plants with CCS. Capital cost increases by an average 63% for PC and 37% for IGCC plants with CCS.

Based on this information, CIMS modelers assume a 90% capture efficiency for IGCC plants, and 85% for conventional combined cycle coal plants. Fuel use per unit of electricity generation would increase by 30% for combined cycle coal with CCS plants and by 19% for IGCC plant with CCS compared to their respective counterparts without CCS.[19]

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[19]In Table 4.2, we also see information pertaining to abatement costs. The cost of abatement specific to CCS is computed as a ratio of incremental product cost (increase in unit electricity cost) to the reduction in per unit CO2 emissions:

$$Cost\, of\, CO_2\, Avoided = \frac{COE_{capture} - COE_{ref}}{(CO_2/kwh)_{ref} - (CO_2/kwh)_{capture}}$$

where $COE_{capture}$ is cost of electricity for a plant with CCS, and COE_{ref} is cost of electricity for the reference plant. This cost includes transport and storage costs and any gains from EOR. The emission factors, $(CO_2/kwh)_{ref}$ and$(CO_2/kwh)_{capture}$ are emissions per kWh of electricity generated for the reference and the capture plants.

To evaluate cost in terms of capture only, the applicable formula is:

$$Cost\, of\, CO_{2\, Capture} = \frac{COE_{capture} - COE_{ref}}{CO_{2\, captrued}/kwh}$$

where $CO_{2\, captrued}/kwh$ is the amount of CO2 captured per kWh of electricity generated.

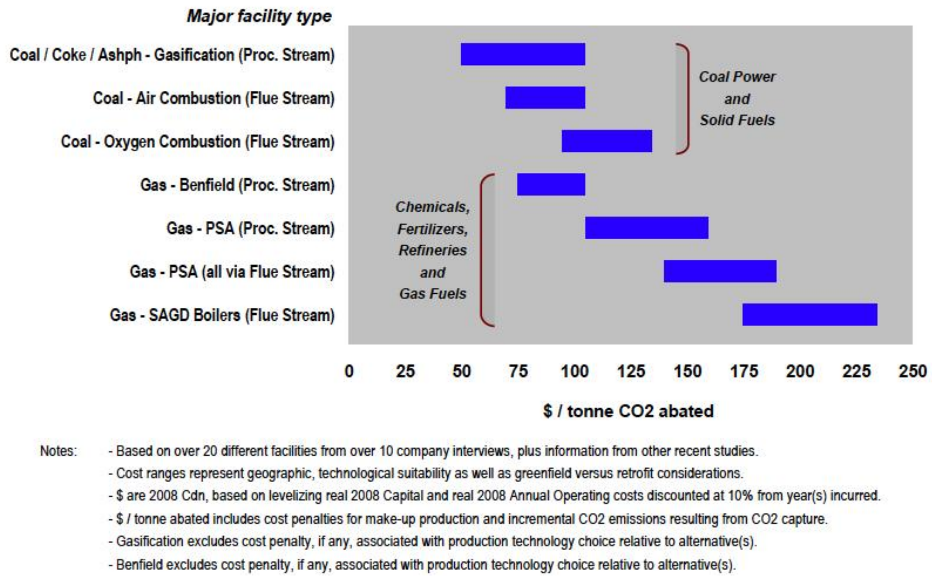
In Table 4.2, the reported net capture cost is computed using the above equation. For example, for the new PC plant, the amount of CO2 captured (the difference between emission per kWh for a plant without capture and a plant with capture) is 0.65 kgCO2/kWh or 0.00065tCO2/kWh. The difference in the costs of electricity is 0.027 US$/kWh. Thus, 0.027 US$/kWh divided by 0.00065tCO2/kWh gives us about US$41/tCO2.

Table 4.2: Summary of CO2 capture costs for new power plants based on current technology, excluding transport and storage costs or benefits from EOR

Performance and cost measures	New NGCC plant			New PC plant			New IGCC plant		
	Range		Rep.	Range		Rep.	Range		Rep.
	Low	High	value	Low	High	value	Low	High	value
Emission rate without capture ($kgCO_2/kWh$)	0.344	0.379	0.367	0.736	0.811	0.762	0.682	0.846	0.773
Emission rate with capture ($kgCO_2/kWh$)	0.040	0.066	0.052	0.092	0.145	0.112	0.065	0.152	0.108
Percentage CO_2 reduction per kWh (%)	83	88	86	81	88	85	81	91	86
Plant efficiency with capture, LHV basis (%)	47	50	48	30	35	33	31	40	35
Capture energy requirement (% increase input/kWh)	11	22	16	24	40	31	14	25	19
Total capital requirement without capture (US$/kW)	515	724	568	1161	1486	1286	1169	1565	1326
Total capital requirement with capture (US$/kW)	909	1261	998	1894	2578	2096	1414	2270	1825
Percent increase in capital cost with capture (%)	64	100	76	44	74	63	19	66	37
COE without capture (US$/kWh)	0.031	0.050	0.037	0.043	0.052	0.046	0.041	0.061	0.047
COE with capture only (US$/kWh)	0.043	0.072	0.054	0.062	0.086	0.073	0.054	0.079	0.062
Increase in COE with capture (US$/kWh)	0.012	0.024	0.017	0.018	0.034	0.027	0.009	0.022	0.016
Percent increase in COE with capture (%)	37	69	46	42	66	57	20	55	33
Cost of net CO_2 captured (US$/t$CO_2$)	37	74	53	29	51	41	13	37	23
Capture cost confidence level (see Table 3.6)	moderate			moderate			moderate		

Note: Costs are stated in constant US$2002. The average capacity factor is 80%. All costs include CO2 compression but not additional CO2 transport and storage costs. Fixed charge factors ranging from 11-16% are added to account for relevant fixed costs.
Source: IPCC (2005), Table TS.3

Figure 4.3: Estimates of CCS Abatement Costs Based on Industry Survey in Alberta



Source: Ian Murray and Co(2008)

Implications of CCS costs for CO2 capture potentials in Alberta

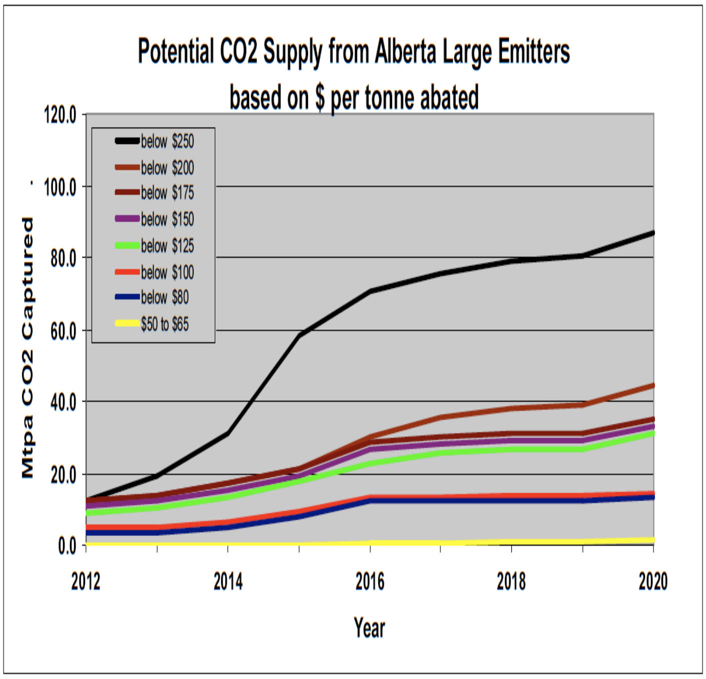
In Alberta, cost estimates based on a survey of 10 companies and public-source information indicates that CCS costs in terms of CO2 abated range between $50/t CO2 to $240/t CO2 (Figure 4.3). According to the same survey by Ian Murray and Co (2008) CCS costs of abatement for coal fired power plants ranges between $60/t CO2 to $150/t CO2 (in 2008$ discounted at 10% from year (s) incurred).[20]

The survey results were also used to estimate Alberta's CO2 capture potentials for each block of $/t CO2 abatement costs. In Figure 4.4, we see that potential CO2 captures in Alberta are quite minimal for abatements costs below $65/t CO2. The overall capture potential in Alberta by 2020 is estimated to be about 85Mt per annum (Mt/year). The capture potential from coal-fired plants is about $30 Mt/year, based on the estimates that the abatement costs for coal-fired plants range between $60 - $150/t CO2 captured, and the observation that the amount captured for abatement costs below $60/t CO2 is negligible.

Note that the increase in the capture potential for each block of abatement costs is related to the estimated increase in CO2 supply (emissions)

[20]The study by Ian Murray and Co was carried out for the Alberta CCS Development Council

Figure 4.4: Alberta CO2 Capture Potentials



Source: Ian Murray and Co. (2008), Appendix 1(b)

in the absence of CCS. Most of the projected increases in CO2 emissions come from oil sand operations, for which CCS abatement costs are above $175/t CO2 (Figure 4.3). This is reflected in the significant gap between the capture potentials pertaining to abatement costs below $200 and $250, receptively. Should a carbon tax regime be applied to induce CCS deployment, the tax has to be as high as the abatement costs implied in Figure 4.3 and the abatement potentials related to these taxes are as highlighted in Figure 4.4.

Technology Learning

CCS technologies are expensive mainly because they are currently at development and demonstration stages. Costs are expected to decline over time due to learning by doing.[21] In the CIMS technology data base, assumptions regarding learning rates were not provided for CCS power plants. However, consideration of technological learning can have a significant in-

[21] There is still relatively little experience with the combination of CO2 capture, transport and storage in a fully integrated CCS system, although separation of CO2 from flue gases has been practiced for many years in industries such as ammonia production, and natural gas sweetening (IPCC, 2005). This is particularly true for the electricity sector (Rubin et al., 2007).

fluence on the expected role of CCS technologies.

An extensive study on various types of technologies by IEA GHG (2006) analyzes historical cost trends and estimates average learning rates for capital costs and operating and maintenance costs for seven technologies that are in some ways analogous to technologies used in power plants with CO_2 capture.[22] Learning rates for operating and maintenance costs, and capital costs were estimated separately. The predicted reductions in capital costs of capture and overall costs of CCS, defined as the cost of a power plant without capture minus the cost of a plant with capture at a point in time, as both plant types benefit from "learning" are, respectively, 20% and 40% for Natural gas combined cycle post combustion capture; 15% and 26% for Pulverized coal post combustion capture; 15% and 26% for IGCC (coal) pre-combustion capture; and 13% for Oxy-combustion plant (coal).[23] We incorporate these estimated learning rates in our baseline forecast. That is, we assume learning rates of 26%.[24]

4.4.2 Baseline Input Data and the Shale Gas Revolution

Baseline Input Data

To initiate simulation using CIMS, base-case macroeconomic forecasts (GDP in each sector, number of households or residential floor space; commercial/institutional floor space; passenger-kilometer traveled; and energy price) are required. The respective market shares of each process and technology at the start of the simulation are based on calibrated values. Starting with these individual baseline forecasts and technology shares, the CIMS algorithm generates equilibrium forecasts for the sectoral outputs, equilibrium energy prices, the corresponding energy demand, technology market shares, and the resultant GHG emissions.

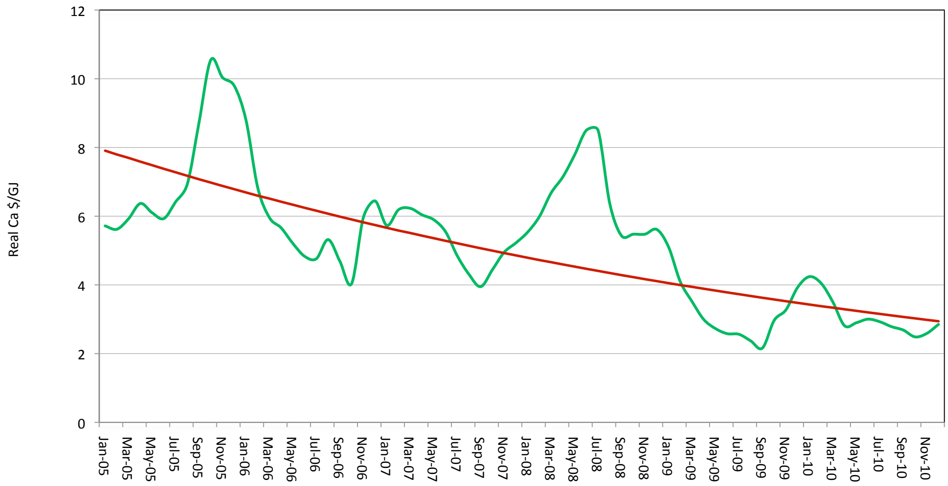
We trace the implied annual growth rates for each sector from the

[22] These are flue gas desulfurization (FGD) in power plants; selective catalytic reduction (SCR) in power plants; pulverized coal boilers; gas turbine combined cycle power plants; liquefied natural gas (LNG) production plants; and oxygen production plants and steam methane reforming (SMR) plants for hydrogen production.

[23] The reason for calculating learning as the decline in the difference in costs of plants with and without CCS is to separate that part of the decline in costs solely attributable to CCS costs.

[24] No learning information was provided for CCS technologies in CIMS.

Figure 4.5: Trends in Real Alberta Reference Natural Gas Price (Ca $/GJ)



Note: Values are nominal prices divided by CPI (2002=1). The Alberta Natural Gas Reference Price is a monthly weighted average field price of all Alberta gas sales, as determined by the Alberta Department of Energy through a survey of actual sales transactions.

tables presented in MKJA (2007) report to compute the baseline input data presented in Tables 4.3 and 4.4.

The Shale Gas Revolution: Natural Gas Price Dynamics and Future Scenarios

Natural gas prices almost doubled during 2005. The reference price was $5.7/GJ in January 2005, hitting double digits in December. This trend continued through the early months of 2006 (Figure 4.5). The implication, at the time, of this trend for forecasted natural gas price was that forecasters tended to expect this trend would continue, thereby leading to high forecasts. This is what we observe in the baseline price forecasts used in the MKJA (2007) report as shown in (Table 4.4). Figure 4.5, however, shows that natural gas prices have been declining since early 2006.

The fact that forecasts made during a period of high natural gas prices tend to be overstated is more clear from the forecasts in the EIA' annual energy outlooks (Figure 4.6). Comparison of forecasts made in 2008 (AEO 2009), 2009 (AEO 2010) and in 2010 (AEO2011) shows high actual prices tend to lead to higher price forecasts while lower actual prices tend to lead to lower price forecasts. Note, however, that forecasts predict that natural

Table 4.3: Reference Energy Demand Drivers

	Units	2010	2015	2020	2025	2030	2035
Demand Sectors							
Residential	thousands of households	1345	1437	1536	1605	1677	1731
Commercial	million m^2 of floarspace	91	99	107	116	125	136
Transportation							
Passenger	billion passenger-km	79	86	94	101	109	116
Freight	billion tonne-km	224	246	271	294	319	346
Manufacturing Industry							
Chemical Products [a]	million tonnes	14	14	15	15	16	16
Industrial Minerals [b]	million tonnes	2	2	3	3	3	3
Pulp and Paper [c]	million tonnes	0.4	0.4	0.4	0.4	0.4	0.4
Other Manufacturing	million $2003	16023	18585	21557	24967	28917	31609
Supply Sectors							
Crude Oil	thousand barrels per day	2302	2302	2302	2302	2302	2302
Conventional Light	thousand barrels per day	306	255	212	190	170	154
Conventional Heavy	thousand barrels per day	155	129.3	107.8	89.6	74.5	65.0
Oil Sands Mining	thousand barrels per day	932	1351	1958	2037	2120	2167
Oil Sands Thermal	thousand barrels per day	909	1174	1516	1696	1897	2100
Natural Gas	billion m^3 [d]	143	132	121	111	102	96
Coal Mining	million tonnes	37	43	50	51	52	54
Electricity Generation	TWh	49	50	52	55	58	63
Petroleum Refining	million m^3	26	28	30	33	36	40
Ethanol	TJ	382	481	607	666	730	828

Notes: [a] chemical product output is the sum of chlor-alkali, sodium chlorate, hydrogen peroxide, ammonia, methanol, and petrochemical production
[b] industrial mineral output is the sum of cement, lime, glass, and brick production
[c] pulp and paper output is the sum of linerboard, newsprint, coated and uncoated paper, tissue and market pulp production
[d] natural gas production includes coalbed methane

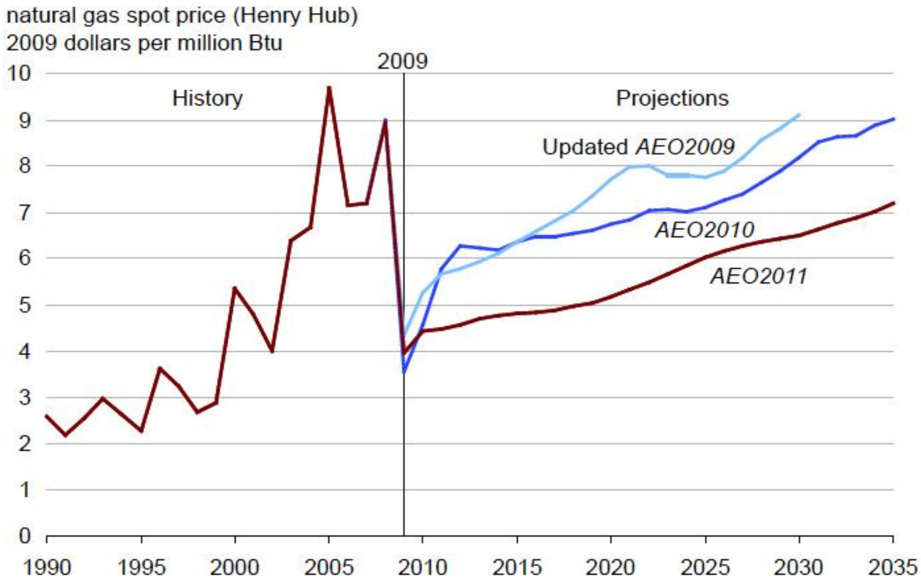
Note: These values are based on prorated growth rates from the price forecasts presented at 10 year intervals in MKJA (2007)

Table 4.4: Reference Energy Prices

	Units	2010	2015	2020	2025	2030	2035
Crude Oil (WTI)	2003$/barrel	52.65	49.50	49.50	49.50	49.50	49.50
Natural Gas							
Industrial	2003/GJ	7.50	7.30	7.10	8.00	9.00	10.14
Residential	2003/GJ	10.05	9.65	9.26	10.42	11.74	13.21
Commercial	2003/GJ	9.22	8.82	8.44	13.87	22.80	17.59
Electricity generation	2003/GJ	7.78	7.59	7.41	8.16	8.97	9.86
Coal							
Market	2003$/GJ	3.23	3.23	3.23	3.23	3.23	3.23
Electricity generation	2003$/GJ	1.17	1.42	1.42	1.42	1.42	1.42
Gasoline	2003$/GJ	19.85	18.27	18.27	18.27	18.27	18.27
Diesel (Road)	2003$/GJ	16.35	15.14	15.14	15.14	15.14	15.14
Electricity	2003$/GJ						
Industrial	2003$/GJ	16.49	15.87	15.87	15.87	15.87	15.87
Residential	2003$/GJ	23.13	24.25	25.43	25.52	25.61	25.68
Commercial	2003$/GJ	17.10	17.55	18.01	18.07	18.14	18.19

Note: These values are based on prorated growth rates from the price forecasts presented at 10 year intervals in MKJA (2007)

Figure 4.6: Comparison of Forecast Natural Gas Prices Based on Year of Forecast



Source: EIA (2011), 2011 Annual Energy Outlook; `http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf`

gas prices will increase in all cases. EIA's short-term outlook, however, suggests that natural gas price is expected to decline in 2011 even though the forecasts are made according to the annual outlooks (Figure 4.6) which predict an increase.[25] This was due to an upward revision of the supply forecast.

The downward trend in natural gas prices during the recent past has been driven by the shale gas revolution, particularly in the US. Since 2000, shale gas production has increased from accounting for only 1% of US production to 20% in 2009, mainly because of technological breakthroughs in horizontal drilling and hydraulic fracturing which made extraction economical (Stevens, 2010). Gross production of natural gas in the US during 2005 - 2009 has been increasing even though production in Canada and Mexico was declining (Table 4.5). In Canada, the National Energy Board (National Energy Board, 2009) reports that, as of July 2009, 234 horizontal wells were producing shale gas from Monteney shale, leading to an increase in shale gas output from zero in 2005 to 376 Million Cubic feet in 2009.

Future prospect suggest that shale gas supply will increase significantly both in Canada and the US. The 2010 International Energy Outlook,

[25] EIA, June 2011 Short-term Energy Outlook,`http://www.eia.gov/emeu/steo/pub/gifs/Fig4.gif`

Table 4.5: Natural Gas Production

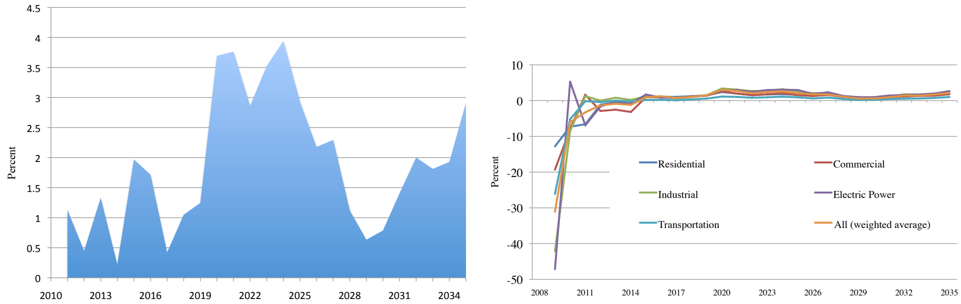
	2005	2006	2007	2008	2009
Canada	7734	7785	7625	7369	6928
United States	23457	23535	24664	25754	26177
North America	32775	33149	34167	35304	34879
World	125242	128590	132903	138091	132409

Source: EIA (2010), 2010 International Energy Outlook,
`http://www.eia.gov/oiaf/ieo/pdf/0484(2010).pdf`

for example, assumes North America's natural gas production will grow by 18 percent over the projection period (Energy Information Administration, 2010). The United States accounts for more than 85 percent of this total production growth, with an increase from 19.2 trillion cubic feet in 2007 to 23.4 trillion cubic feet in 2035 and a fivefold increase in total production due to shale gas production that is expected to more than offset the forecast decline in conventional gas. Canada's natural gas production is expected to decline from 6.3 trillion cubic feet in 2007 to 5.5 trillion cubic feet in 2020, followed by production increases as the exploitation of shale gas, tight gas, and coal bed methane resources reverses the decline in overall production leading to an increase in total production of 6.7 trillion cubic feet in 2035. Mexico's natural gas production remains fairly flat in these projections, growing only from 1.8 trillion cubic feet in 2007 to 2.1 trillion cubic feet in 2035. Growth in prices is projected despite these projected increases in in supply because of forecasts regarding increased demand (Energy Information Administration, 2011). The 2011 Annual Energy Outlook, in particular, projects that natural-gas fired electricity generation will expand in the US (Energy Information Administration, 2011).

More recent forecasts of natural gas prices take this shale gas scenario into consideration. Even though natural gas prices are forecast to increase even with the shale gas revolution, mainly due to the assumption of increases in demand and decreases in drilling, both driven by low prices, the projection is that the growth in price will be very modest and significantly less than the forecasts generated without taking the shale gas supply into consideration (Energy Information Administration, 2010; 2011). Hence, natural gas price assumptions used in the CIMS report (2007) shown in Table 4.4 are very high, mainly because the shale gas revolution was not taken into account at the time the forecasts were made, and also that the benchmark year (2005/2006) for the forecasts was characterized by very

Figure 4.7: Henry Hub Spot (wholesale price) and End-use Natural Gas Price Forecast Growth Rates



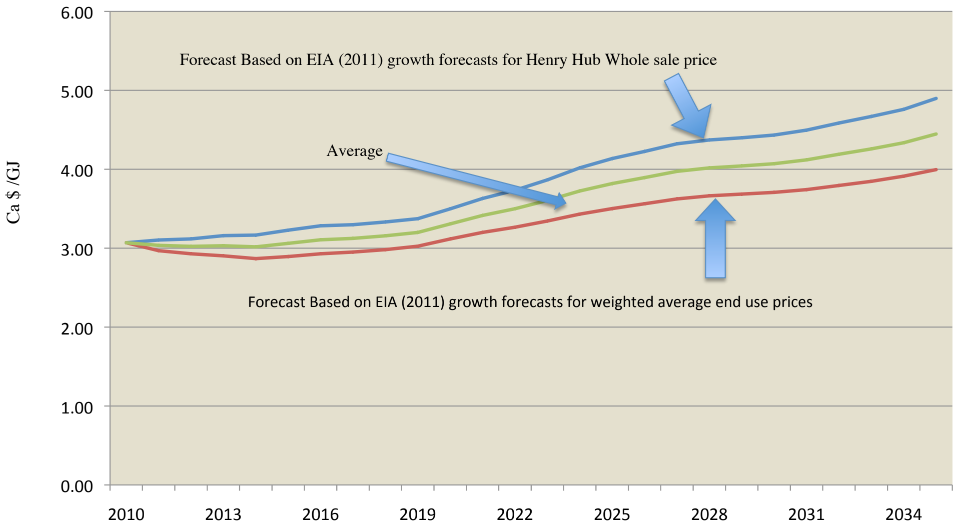
Source: Computed from EIA (2011), 2011 Annual Energy Outlook. Left Panel is growth rate in wholesale price while right panel is growth rates in end-use prices

high natural gas prices (Figure 4.7).

As a result of these observations, we construct forecasts of Alberta reference natural gas price based on the growth rates computed from Energy Information Administration (2011) forecasts. There are two types of natural gas prices forecasted, the Henry Hub Wholesale Price and the end-use price. As shown in Figure 4.7, the forecast annual growth rates in the whole sale price fluctuate significantly while that of the end-use price are relatively stable. As the right panel of Figure 4.7 shows, the forecast growth rates in natural gas prices applicable to each end-use sector and their weighted average remain stable after 2015, although some fluctuations were predicted before that.

We construct our forecast for Alberta Reference Natural Gas Price based on both of these growth rates (the growth rates in the wholesale and average weighted end-use prices) for the years 2011 - 2035 (Figure 4.8). Figure 4.8 presents the Alberta reference price forecasts based on these growth rates and the average forecast. We observe that the two growth rate assumptions generate two distinct natural gas price forecasts which we consider as the high and low forecast scenarios. For our analysis, we use the average of these two forecasts as our baseline input data for natural gas price. According to our forecast, Alberta reference (real) natural gas price remains unchanged during the period 2011 - 2014, and starts to rise afterwards. The price remains below the $5/GJ mark over the entire forecast period.

Figure 4.8: Forecast Alberta Reference Natural Gas Price Scenarios ($/GJ)



Note: The projection is based on historical Alberta Reference Real Price ($/GJ) and growth rates computed from EIA (2011)

4.5 Analysis and Results

4.5.1 Simulation Scenarios

We begin our analysis of the electricity sector by outlining a base case that reflects business-as-usual behaviour. We assume that CCS power plants will be online in 2015. Being a new technology, costs are assumed to decline overtime due to learning by doing. We analyze three policy scenarios under both price assumptions, all of which can be considered CCS policies. The first is a carbon tax regime starting at $50/t in 2010 and escalating to $200 in 2035. The minimum tax considered is equivalent to the minimum abatement cost associated to CCS adoption as shown in Figure 4.3. We, then, consider two alternative policies (explained in detail below), dirty coal control and 50% subsidy for CCS costs (Table 4.6).

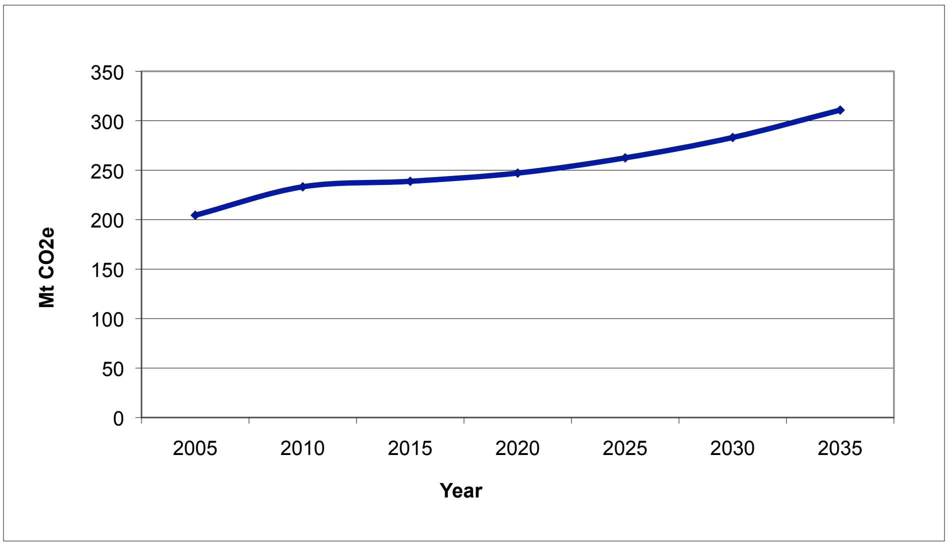
We consider the existing specified gas emitters regulation with the underlying carbon tax of $15/t and the high natural gas price assumed when the Alberta action plan was issued to be part of our baseline scenarios. We evaluate the effects of the shale gas revolution both on this business as usual forecast and the policy scenarios considered.

Our baseline forecast suggests that overall Alberta GHG emissions could reach 311 Mt CO2e by 2035 (Figure 4.9). About 44 Mt CO2e would

Table 4.6: Description of the scenarios simulated

Simulation Scenarios	Description
Business As Usual # 1	Prices assumed as in Table 4; A carbon Tax of $15/t included according to the specified gas emitters regulation; CCS learning rate of 26%
Business As Usual # 2 (Shale Gas Revolution)	All else same as above except that the low natural gas price forecast is used in this case
Scenario #1-1	Given the base case with HIGH natural gas price scenario, we simulate a Carbon Tax ranging between $50 during 2011 - 2015; $75 during 2016 - 2020; $125 during 2021 - 2025; $175 during 2026 - 2030; and $200 during 2031 - 2035 (the carbon tax range is specified according to the relevant abatement cost range in Figure 4.3)
Scenario #1 - 2	Given the base case with LOW natural gas price scenario, we simulate a Carbon Tax ranging between $50 during 2011 - 2015; $75 during 2016 - 2020; $125 during 2021 - 2025; $175 during 2026 - 2030; and $200 during 2031 - 2035
Scenario # 2 -1	Given the base case with HIGH natural gas price scenario, we simulate a CCS subsidy of 50% of the total capital cost
Scenario # 2 -2	Given the base case with LOW natural gas price scenario, we simulate a CCS subsidy of 50% of the total capital cost
Scenario # 3 - 1	"Dirty Coal" Control by 2015 under the HIGH natural gas price case: All coal fired power plants would be required to install CCS or exit (A policy of shutting down conventional coal plants was enacted in Ontario, for example)
Scenario # 3 - 2	"Dirty Coal" Control by 2015 under the LOW natural gas price case: All coal fired power plants would be required to install CCS or exit

Figure 4.9: Forecast Business as Usual GHG Emissions For Alberta



be generated by the electric power generation sector. Generally, the reference case simulation results under the high natural gas price show that the existing policy, the specified gas emitters regulation of \$15/t, is not aggressive enough to bring about significant changes in CO2 emissions or CCS market penetration in the electric power generation sector. With this low carbon tax level, CCS gradually enters the market, capturing only about 10% by 2035 (Table 4.8). The shares of coal would decline slightly over time because of competition from natural gas, renewables and also CCS. The main reason for increases in renewables and CCS market shares over time under this low carbon tax regime are the assumptions that costs of both CCS and renewables decline over time due to learning by doing. In the next section, we evaluate the effects of the shale gas revolution on both the baseline forecasts and effects of various policy scenarios.

4.5.2 The effects of the Shale Gas Revolution

4.5.2.1 The reference case

A high natural gas price assumption is inherently favorable toward CCS in that it negatively affects the competitiveness of natural gas-fired plants and permits coal CCS to gain a cost advantage. The natural gas market has, however, significantly changed recently due to the shale gas revolution. When we take this change into account, the first thing to note is that our reference case results fundamentally change. This is what we demonstrate in this section.

With the high natural gas price assumption, the share of coal is generally larger than the estimated share under the low natural gas price assumption. Estimated CO2 intensity and emissions levels are, therefore, lower under the low natural gas price assumption. The share of CCS that was 6% in 2015 under the high natural gas price falls to 4% in the low natural gas price scenario (Table 4.7). Because the market shares are computed based on cost comparisons, this reflects the fact that CCS faces less of a cost disadvantage under the high natural gas price assumption. This has important implications for CCS adoption and GHG abatement policies, as CCS becomes a more costly abatement strategy under the low natural gas price scenario.

Table 4.7: Comparison of Reference Case Results

		2010	2015	2020	2025	2030	2035
High Natual Gas Price	**GHG Emissions (Mt Coe)**						
	All Sectors	233	239	247	262	283	311
	Electricity Sector	47	36	31	30	31	33
	Emission intensity of electricity generation (t/GJ)	0.28	0.22	0.17	0.15	0.14	0.14
	Fuel Consumption (PJ) - all sectors						
	Coal (PJ)	634	664	717	784	869	964
	Natual Gas (PJ)	1609	1701	1758	1798	1836	1854
	Refince Petroleum (OIL) (PJ)	544	624	712	834	978	1181
	Electricity	262	271	280	294	317	345
	Fuel Mix (Market Shares) in Electriciy Generation (%)						
	Coal	65	57	42	45	49	51
	Coal CCS	0	6	9	10	10	11
	Natual Gas	30	35	44	38	33	30
	Renewables (Wind, Hydro, others)	5	9	12	13	13	14
Low Natual Gas Price	**GHG Emissions (Mt Coe)**						
	All Sectors	233	239	247	261	281	306
	Electricity Sector	47	36	30	29	29	31
	Emission intensity of electricity generation (t/GJ)	0.28	0.22	0.16	0.14	0.14	0.13
	Fuel Consumption (PJ) - all sectors						
	Coal (PJ)	626	652	682	728	783	839
	Natual Gas (PJ)	1757	1941	2098	2266	2471	2690
	Refince Petroleum (OIL) (PJ)	436	461	491	527	563	630
	Electricity	258	263	269	280	296	315
	Fuel Mix (Market Shares) in Electriciy Generation (%)						
	Coal	33	29	12	20	20	21
	Coal CCS	0	3	3	5	5	5
	Natual Gas	63	64	80	69	69	66
	Renewables (Wind, Hydro, others)	4	4	5	7	7	8

Another important anticipated effect of the shale gas revolution is a shift away from renewables.[26] The shares of renewables diminish as they face competition from low cost natural gas. The concerns regarding the negative impacts of the shale gas revolution on renewables appears to be supported by our results. Even though it reduces the role of renewables in Alberta, the overall effect is positive in the sense that the increase in natural gas-fired electricity is significantly larger and therefore the CO2 intensity of electricity consumption in Alberta declines.

Needless to say, coal consumption is generally less under the low natural gas price scenario while natural gas consumption is larger. Alberta, being endowed with both resources, may not experience economic costs in terms of job losses due to this shift in demand from one sector of the economy to another. The negative impact on the coal sector is, however, notable.[27] In the following subsections, we analyze the effects of three policy scenarios, emphasizing the effects of the shale gas revolution on the outcomes of the policies.

[26] One of the most widely expressed concerns with the shale gas revolution is its potential to kill renewables (e.g. `http://www.ottawacitizen.com/news/Cheap+shale+kills+renewable+resources+energy+price/4960456/story.html`).

[27] This statement assumes that supply is demand driven. Given that Alberta consumes about 80% of its coal production, rises and falls in domestic consumption have a profound effect on production.

4.5.2.2 Carbon Tax

The theoretical underpinnings for a carbon tax are well known. Roughly speaking, the tax should be set at a rate equal to the marginal social cost of carbon. In this manner, an unpriced input into the production process receives a value that firms must now pay. The increased cost of using clean air as a waste facility causes firms to rationalize on their use of the now more expensive input.

In this subsection, we provide comparisons of the results for the tax policy scenario. We observe that CO2 emissions significantly decline under the tax regime relative to the reference case (Table 4.9). Generally speaking, emission taxes generate equivalent results in terms of the effects on CO2 emissions under the two price scenarios (Table 4.8). The main difference is related to how the reductions are achieved. First, note that the carbon tax could be used to remove all dirty coal electricity generation from the economy. In the high natural gas price case, a carbon tax of about $125/t would be needed to eliminate dirty coal while a $75/t tax would be enough under low natural gas prices.

In Table 4.8, we express carbon tax rates in terms of dollars per GJ of electricity generated, based on the CO2 intensity of electricity generation in the reference cases (see Table 4.7). We compare these to the per unit cost of electricity generation in the reference cases (under both the low and high natural gas price scenarios). A $50/t carbon tax during 2010 - 2015 adds about $11/GJ to the cost of electricity under both natural gas price scenarios. A $200/t tax adds about $26/GJ and $28/GJ, respectively under the low and high natural gas prices. This more than doubles the cost of electricity. Thus, we observe that the effects of these carbon taxes on electricity costs are large. There is a slight advantage in this respect in the low natural gas price scenario because larger reliance on natural gas will reduce the carbon intensity of electricity generation.

The carbon tax leads to a significant increase in CCS market shares. Under the high natural gas price scenario, the share would be 26% at a carbon tax rate of $50/t in 2015, compared to 15% under the low natural gas price scenario. The highest market share at the high carbon tax of $200/t would be 45% with the high natural gas price scenario. This would be only 29% under the low natural gas price case (Table 4.9). This indicates

Table 4.8: Reference case electricity prices and carbon tax per GJ of electricity

	2010 -2015	2015 -2020	2020-2025	2025-2030	2030-2035
Emisison tax ($/ tonne)	50	75	125	175	200
Reference Electricity price ($/GJ) -High natural gas price	20	22	24	25	26
Reference Electricity price ($/GJ) -Low natural gas price	18	20	22	22	23
Emission tax ($/GJ of electricity) - High natural gas price case	11	13	19	25	28
Emission tax ($/GJ of electricity) - Low natural gas price case	11	12	18	25	26

the important role played by natural gas in reducing emissions, with low prices resulting in increased uses, thereby reducing CO2 emissions.

While a carbon tax raises the market shares of renewables significantly, low natural gas prices have the effect of significantly constraining this impact, particularly in the short-term. The share of renewables would jump to 32% in 2015 under the high natural gas price scenario. In the low natural gas price case, this would be only 17%. In the long run, however, there is not much difference in the market shares of renewables. By 2030, for example, renewables account for 43% under the high natural gas price scenario while they accounts for 40% under the low natural gas price scenario. This is due to two factors operating simultaneously. The first is that the share of natural gas appears to start to diminish after hitting its maximum potential. The second is that costs of renewables decline over time due to learning by doing.

In the high natural gas price environment, the immediate effect of a carbon tax is to raise the share of natural gas despite the assumed high natural gas price, pending gradual market penetration of alternative technologies, namely CCS coal and renewables. This is important to note because it entails that natural gas is acting as an alternative mechanism for reducing GHG emissions in the short term while the other two are long-term solutions. The reduction in natural gas prices due to the shale gas revolution would more than double this potential of natural gas to act as a CO2 abatement mechanism. The share of natural gas in 2010 under the high price scenario is 30% compared to the 63% share in the low natural

Table 4.9: Comparison of Simulation Results for Carbon Tax Policy

		2010	2015	2020	2025	2030	2035
High Natural Gas Price	**GHG Emissions (Mt CO2e)**						
	All Sectors	233	218	221	205	198	195
	Electricity Sector	48	33	33	28	20	18
	Emission intensity of electricity generation (t/GJ)	0.20	0.14	0.14	0.11	0.07	0.06
	Fuel Consumption (PJ) - all sectors						
	Coal	754	732	788	848	891	930
	Natual Gas	1524	1646	1724	1820	1933	2102
	Refince Petroleum (OIL)	540	586	632	681	728	772
	Electricity	247	250	257	271	296	326
	Fuel Mix (Market Shares) in Electriciy Generation (%)						
	Coal	65	6	2	0	0	0
	Coal CCS	0	26	28	33	34	34
	Natual Gas	30	36	35	27	23	21
	Renewables (Wind, Hydro, others)	5	32	35	40	43	45
Low Natural Gas Price	**GHG Emissions (Mt CO2e)**						
	All Sectors	232	217	221	204	198	195
	Electricity Sector	47	32	33	27	20	18
	Emission intensity of electricity generation (t/GJ)	0.20	0.14	0.13	0.10	0.07	0.06
	Fuel Consumption (PJ) - all sectors						
	Coal	734	710	754	788	795	812
	Natual Gas	1677	1840	1959	2095	2255	2456
	Refined Petroleum (OIL)	433	452	478	506	532	564
	Electricity	244	244	248	255	271	296
	Fuel Mix (Market Shares) in Electriciy Generation (%)						
	Coal	33	4	1	0	0	0
	Coal CCS	0	15	18	27	29	29
	Natual Gas	63	64	58	38	32	29
	Renewables (Wind, Hydro, others)	4	17	23	35	40	42

gas price case.

The result also suggests that higher carbon taxes are needed for CCS to be able to compete with natural gas. In both price scenarios, we observe that CCS market shares increase, eating into the share of natural gas as the carbon tax increases over time (Figures 4.10 and 4.11). In 2035, at a carbon tax of \$200/t, the shares of CCS are estimated to be 34% in the high natural gas price scenario compared to 29% in the low natural gas price case. This 5 percentage point difference suggests that a higher carbon tax would be needed to achieve full CCS deployments under low natural gas price. In other words, the GHG emission reduction targets could be more stringent such that natural gas burning itself can be penalized via the tax.

Under the high natural gas price scenario, the share of natural gas would only slightly increase and then be reversed as soon as the carbon tax is raised to about \$50/t. Its high cost would not allow it to compete with CCS and renewables when carbon taxes are increased. This is because natural gas is less clean relative to CCS coal and renewables so that it would lose its cost advantages at very high carbon tax rates.

A comparison of cumulative emission reductions due to CCS market

Figure 4.10: Market Shares Under Tax Policy in High Natural Gas Price Scenario

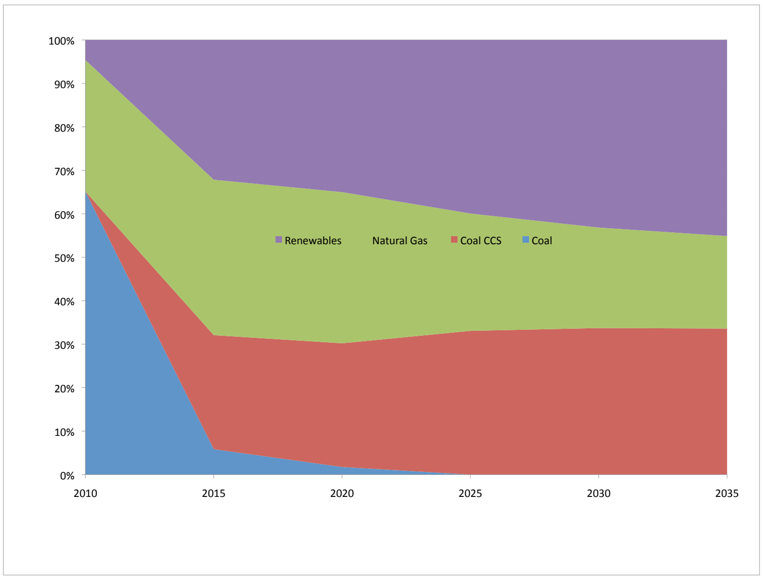


Figure 4.11: Market Shares Under Tax Policy in Low Natural Gas Price Scenario

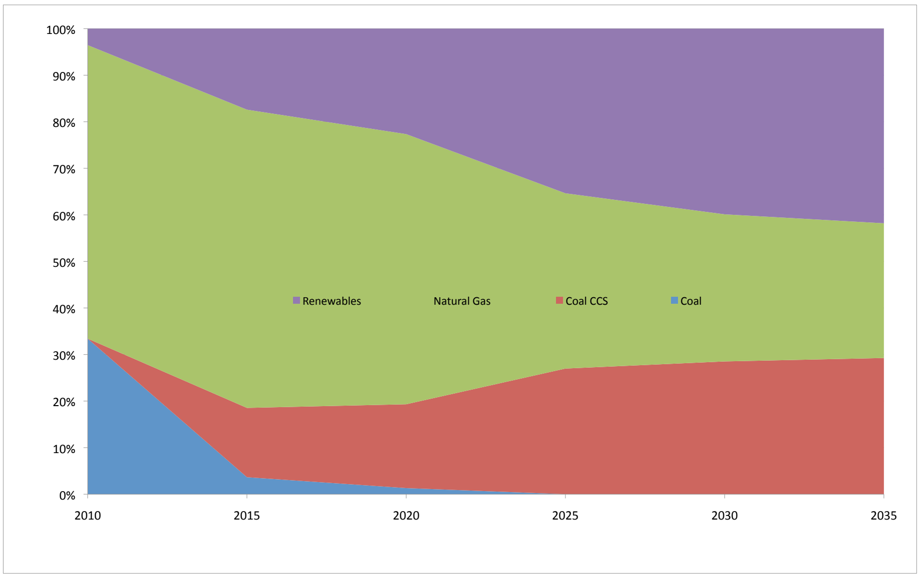
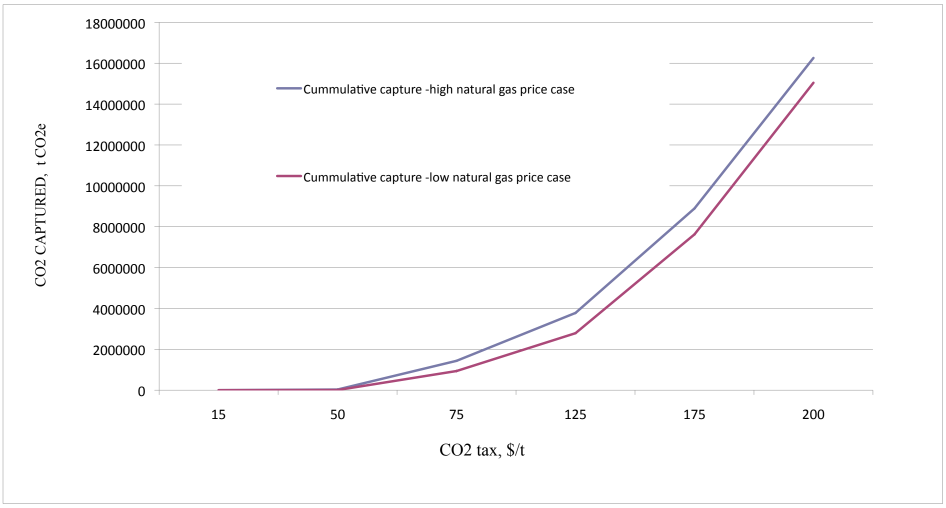


Figure 4.12: Cumulative CO2 Captures Under CO2 Tax Policy



penetration indicates differential effects of a carbon tax under the two price scenarios. As expected, CO2 abatement potentials using CCS would be limited due to the shale gas revolution. The difference is about 1 Mt CO2e in general. Hence, we conclude that the reduction in natural gas prices would reduce CCS potential as an abatement mechanism by this magnitude. As a side note, we observe in Figure 4.12 that the cumulative CO2 capture curve becomes steeper after a carbon tax of $125/t, suggesting that incremental taxes beyond this tax level would have significant impacts on CO2 capture.

4.5.2.3 CCS Cost Subsidy

Subsidization of CCS has been an approach chosen by the Alberta government to achieve fast and widespread application of these technologies. The subsidy amount we simulate is 50% of a CCS coal plant capital cost. The exact subsidy amount for combined cycle coal plants with CCS is $614,481,243 and $389,059,972 for IGCC plants. Costs are discounted at 35% while technology life is assumed to be 30 years.[28] Given the specific generation capacities this subsidy is about $12 per GJ of electricity.

The amount of subsidy considered here appears to be extremely high. Yet, we observe that, even this amount of subsidy, is not enough to bring about complete replacement of "dirty" coal-fired plants with CCS coal

[28]Practically, a CCS subsidy amounting to over $700 million has been pledged for the "project pioneer" with 100 MW capacity, expected to capture about 1Mt/year.

Table 4.10: Comparison of Results for CCS Subsidy Policy

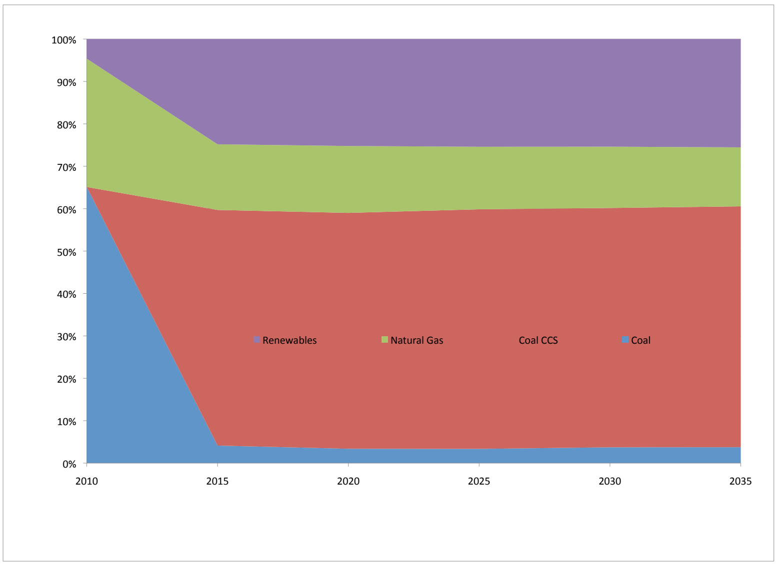
		2010	2015	2020	2025	2030	2035
High Natural Gas Price	**GHG Emissions (Mt CO2e)**						
	All Sectors	233	238	245	258	276	300
	Electricity Sector	48	47	39	36	34	32
	Emission intensity of electricity generation (t/GJ)	0.28	0.28	0.21	0.18	0.16	0.14
	Fuel Consumption (PJ) - all sectors						
	Coal	634	667	740	825	927	1037
	Natual Gas	1609	1699	1748	1782	1815	1830
	Refined Petroleum (OIL)	544	624	712	833	977	1179
	Electricity	262	271	280	294	317	345
	Fuel Mix (Market Shares) in Electriciy Generation (%)						
	Coal	65	4	3	3	4	4
	Coal CCS	0	56	56	56	56	57
	Natual Gas	30	15	16	15	14	14
	Renewables (Wind, Hydro, others)	5	25	25	25	25	26
Low Natural Gas Price	**GHG Emissions (Mt CO2e)**						
	All Sectors	233	239	245	258	276	299
	Electricity Sector	47	46	39	35	34	32
	Emission intensity of electricity generation (t/GJ)	0.28	0.27	0.23	0.19	0.17	0.15
	Fuel Consumption (PJ) - all sectors						
	Coal	626	657	718	795	882	971
	Natual Gas	1757	1937	2074	2224	2409	2610
	Refined Petroleum (OIL)	436	461	491	527	563	630
	Electricity	258	263	269	280	296	315
	Fuel Mix (Market Shares) in Electriciy Generation (%)						
	Coal	33	4	3	3	3	3
	Coal CCS	0	50	47	52	52	52
	Natual Gas	63	24	29	22	22	21
	Renewables (Wind, Hydro, others)	4	22	21	23	23	24

plants under either price scenario. One clear impact is, however, the share of CCS in the short term under this policy scenario is significantly larger than what we observed under the tax policy. Hence, a CCS subsidy helps to speed up CCS deployments.

It appears that all the incremental gains in market shares for CCS in the high natural gas price scenario are from the "dirty" coal share. In the low natural gas price scenario, a CCS subsidy helps CCS to compete with natural gas and a significant proportion of the increment in CCS market shares come from the natural gas market shares (Figures 4.13 and 4.14). Nevertheless, the CO2-reducing impacts of CCS are very limited under both price scenarios. As shown in Table 4.10, electricity sector CO2 emissions are not significantly reduced either relative to the base year (2010) or with respect to the reference case emissions presented in Table 4.7.

The main reason for this is that a CCS subsidy would severely constrain renewables. A CCS subsidy would enable CCS plants to crowd out other low emission-intensity power generation types such as natural gas and renewables. A carbon tax, on the other hand, creates a cost disadvantage for CO2-intensive power generation types, thereby creating a favorable situation for the less CO2-intensive plant types. As shown in Table 4.10, the maximum market shares for renewables under a CCS subsidy is 26% compared to about 45% under the carbon tax regime. A CCS subsidy is not, therefore, a policy that leads to more emission reductions in Alberta. In

Figure 4.13: Market Shares Under CCS Subsidy, High Natural Gas Price



the low natural gas price environment, the potential for a CCS subsidy to reduce CO2 emission is a further limited, as can be seen in Figure 4.15.

As such, one can consider a CCS subsidy as a subsidy for the coal sector instead of a CO2 reduction policy. Should taxes be used to reduce CO2 emissions, coal would suffer the most. Under the CCS subsidy however, coal consumption in the long-run would be larger than the business as usual forecasts under either price scenario.

The effect of the shale gas revolution on a CCS subsidy policy is related to the observation that the CCS subsidy would be used to crowd out natural gas and renewables, a transition with no environmental benefits. Under the high natural gas price scenario, a CCS subsidy would largely lead to displacement of 'dirty' coal plants by CCS plants, with associated environmental gains. This suggests that a CCS subsidy policy may not be supported as an abatement strategy under the low natural gas price scenario. Generally speaking, subsidization of CCS implies that Albertans are paying to ensure that the coal sector remains a major fuel source for electricity generation. The shale gas revolution is shown to have remarkable implications for this strategy.

Figure 4.14: Market Shares Under CCS Subsidy, Low Natural Gas Price

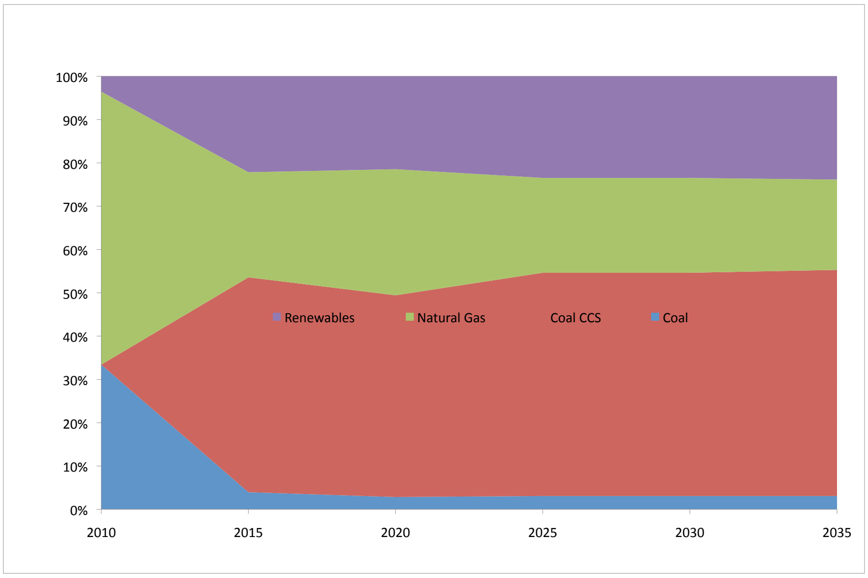
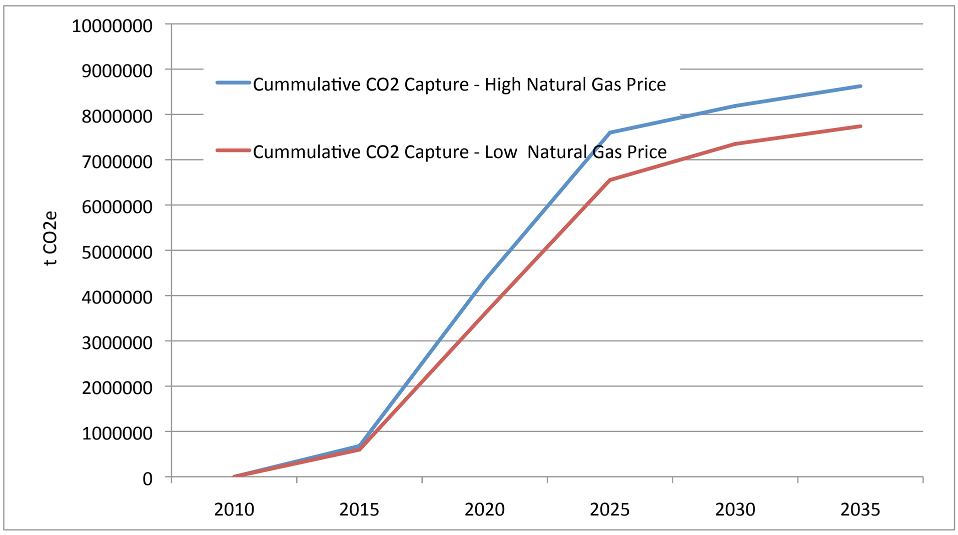


Figure 4.15: Cumulative CO2 capture under CCS subsidy policy



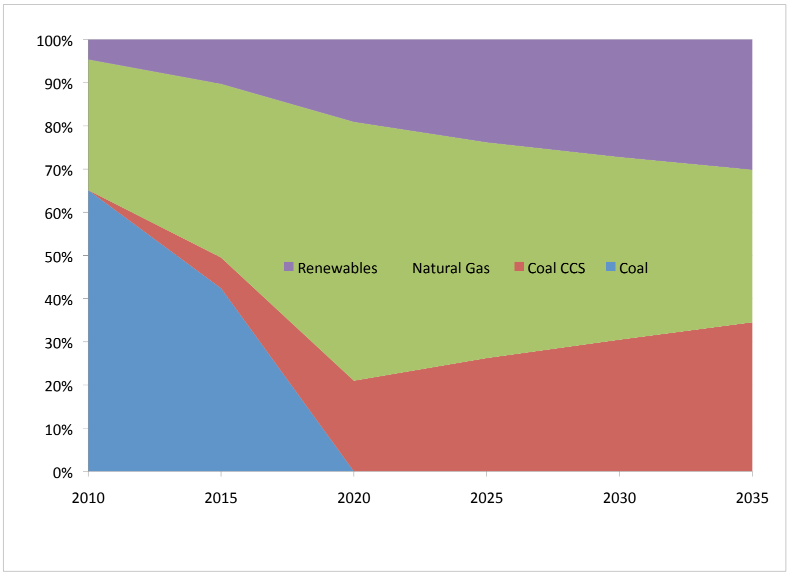
4.5.2.4 Coal Control

A third policy alternative, the policy of banning 'dirty coal' plants after 2015 is also considered. This is a policy similar to Ontario's policy of gradual decommissioning of coal-fired generation by 2014.[29] We consider this mechanism since our results suggest that dirty coal cannot be eliminated via subsidy. In the event that taxes may not be favored, the most obvious alternative mechanism is to implement this strategy. In this case, we impose a mandate of zero dirty coal by the end of 2015. The impact of such a mandate is very different from that which occurs via a subsidy. Under such a policy, there is no specific requirement as to which other generation types would provide the replacements such that coal-fired with CCS, natural gas-fired, and renewables would all compete for available market share. Thus, this policy is a strong CO2 emission reduction strategy since it removes dirty coal from the market. However, it should not be considered a CCS implementation strategy since it does not create a specific incentive for CCS adoption.

Our simulation results for this policy scenario suggests that the immediate effect is to substantially raise the market share of natural gas-fired power plants. As the cost of CCS declines over time, due to learning by doing, CCS market shares would increase in the long run. This pattern, however, depends very much on natural gas prices. Although we observe notable market penetration of CCS under the high natural gas price scenario, this is almost absent in the low natural gas price scenario (Figures 4.16 and 4.17). We see in Figure 4.18 that the carbon capture potential under this policy is very limited under low natural gas prices. This is because the policy does not involve financial incentives (taxes that punish 'dirty coal' and natural gas or a subsidy for CCS). In this case, even if 'dirty coal' is removed, it would be replaced by cheaper alternatives and CCS is not

[29] Government of Ontario (September 3, 2010); Ontario's Coal Phase Out Plan, `http://www.news.ontario.ca/mei/en/2009/09/ontarios-coal-phase-out-plan.html`. A very important policy concerning coal-fired power plants was, however, announced on June 23, 2010 by the Federal Government of Canada. According to the new regulation, to be in effect by July 1, 2015, power companies would have to close their coal-fired facilities at 45 years of age or at the end of the power purchase agreement, whichever is later which implies that companies would be prohibited from making investments to extend the lives of those plants unless emission levels can be reduced to those of natural gas combined cycle plants. The new regulation encourages electric utilities to transition towards lower or non-emitting types of generation such as high-efficiency natural gas, renewable energy, or thermal power with carbon capture and storage (CCS).

Figure 4.16: Market Shares Under "Dirty Coal Control, High Natural Gas Price Case



one of them.

An interesting result is that the GHG emission trajectory under this policy is quite similar to the path observed under the CCS subsidy policy scenario. In the high natural gas price case, emission reduction is achieved via market penetration of both CCS and renewables. With low natural gas prices, emissions are reduced via widespread use of natural gas. This policy, therefore, has some desirable features relative to the alternatives to the extent that Alberta is endowed with natural gas resources that would imply that the increase in natural gas demand could compensate for the temporary loss in coal production.

4.6 Conclusions

Our analysis suggests that the shale gas revolution has made CCS adoption obsolete in Alberta. Even with substantial subsidies, CCS adoption is dominated by natural gas and renewables in the electricity supply sector. Emission reduction objectives are met if environmental policy employs a carbon tax.

The big winner from lower natural gas prices is of course natural gas fired electricity generation. While the coal sector is impacted negatively,

Table 4.11: Comparison of Results for “Dirty” Coal Control Policy

		2010	2015	2020	2025	2030	2035
High Natural Gas Price	**GHG Emissions (Mt Coe)**						
	All Sectors	233	239	246	259	277	302
	Electricity Sector	48	48	48	46	45	44
	Emission intensity of electricity generation (t/GJ)	0.30	0.28	0.29	0.25	0.23	0.20
	Fuel Consumption (PJ) - all sectors						
	Coal	634	664	695	740	801	876
	Natual Gas	1609	1701	1774	1830	1881	1910
	Refince Petroleum (OIL)	544	624	713	836	981	1185
	Electricity	262	271	280	294	317	344
	Fuel Mix (Market Shares) in Electriciy Generation (%)						
	Coal	65	42	0	0	0	0
	Coal CCS	0	7	21	26	30	35
	Natual Gas	30	40	60	50	42	35
	Renewables (Wind, Hydro, others)	5	10	19	24	27	30
Low Natural Gas Price	**GHG Emissions (Mt Coe)**						
	All Sectors	233	239	247	260	278	303
	Electricity Sector	47	37	30	27	27	28
	Emission intensity of electricity generation (t/GJ)	0.29	0.22	0.18	0.15	0.14	0.13
	Fuel Consumption (PJ) - all sectors						
	Coal	626	652	671	699	736	772
	Natual Gas	1757	1941	2107	2289	2508	2744
	Refince Petroleum (OIL)	436	461	491	527	564	631
	Electricity	0	263	269	280	296	315
	Fuel Mix (Market Shares) in Electriciy Generation (%)						
	Coal	33	19	0	0	0	0
	Coal CCS	0	4	3	6	6	8
	Natual Gas	63	73	93	86	86	84
	Renewables (Wind, Hydro, others)	4	5	4	8	8	8

Figure 4.17: Market Shares Under the "Dirty Coal" Control Policy, Low Natural Gas Price

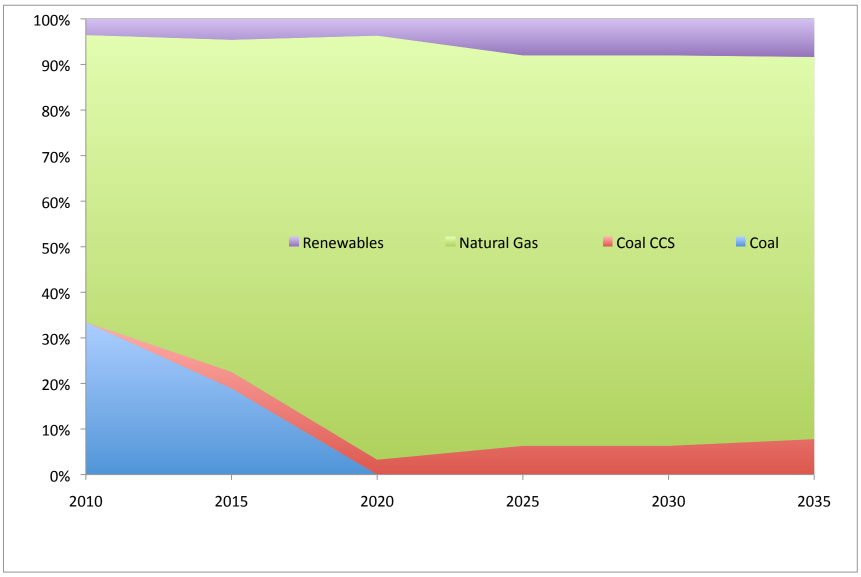
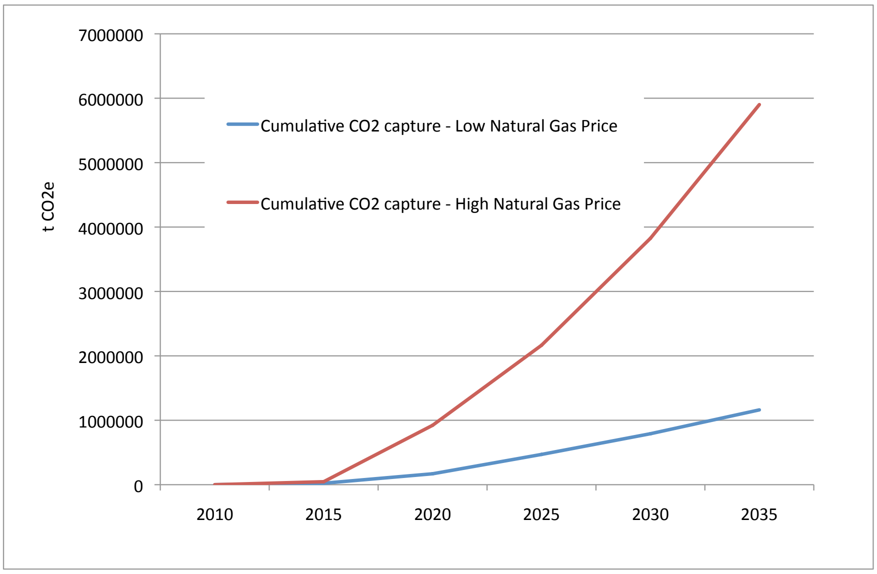


Figure 4.18: Cumulative CO2 Capture Under the "Dirty Coal" Control Policy



Alberta can still benefit to the extent that these generation facilities use Alberta natural gas. This option is a much cheaper way of achieving the twin goals of environmental improvement and the continued prosperity of Alberta's energy sectors. Implementing the policy of 'dirty coal' control under the low natural gas price scenario would lead to a total collapse in the coal production sector since CCS coal cannot compete with cheap natural gas. In this environment, a CCS subsidy is simply a subsidy for the coal sector rather than an environmental policy.

Note, however, that our analysis is limited to the electricity sector. The implications of the shale gas revolution for CCS strategy in other sectors, particularly oil sands operations, requires a separate investigation. Given that oil sands operations utilize natural gas for steam and electricity production, CCS in this sector is applied to natural gas. In this situation, therefore, cheap natural gas might have positive effects on CCS adoption because it reduces overall costs of production.

Future work could also look at the learning rate which would be required in order to make CCS subsidization an economically desirable option. This could be accomplished by running simulation for various learning rate assumptions with the CCS cost subsidy in the context of the low natural gas price scenario.

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Chapter 5

Summary and Conclusions

We have presented three chapters that provide empirical studies focusing on energy efficiency and environmental policies in Canada, each chapter focusing on a distinct topic. The first study focuses on empirical analysis of the EGH program in Canada. In 1998 the Canadian government introduced the EnerGuide for Houses (EGH) program, essentially consisting of home energy audits with financial incentives provided to the homeowner upon verification that sufficient auditor-recommended upgrades were undertaken to achieve energy savings. In this study, we analyze the EGH data compiled between October 1998 and September 2005 to determine (i) what types of households chose to participate; (ii) what are the main types of retrofits chosen, and (iii) what appear to be the main factors that contributed to only a portion of the households that completed the first audit actually undertaking retrofits and which types of households were most likely to do so. We model both the probability and the intensity of retrofit decisions. We find that energy cost savings, financial incentives, and costs of retrofits are important factors behind retrofit decisions given several other home- and household-specific characteristics.

In the second study, we have focused on price-induced energy efficiency improvements in the manufacturing sector. We tackle the problem of estimating price-induced energy efficiency improvements by considering that investment in energy-efficient equipment and machinery is based in part on expectations regarding the future flow of benefits from energy costs saved. Expectations among business managers about future energy prices can be greatly influenced by energy price forecasts released by various institutions such as the US Department of Energy's Energy Information Administration. There has been, however, significant variation between such forecasts and realized energy price trends, and it is these realized trends that have been traditionally used to model energy efficiency. In this paper, we estimate the relationship between expected energy prices, to the extent that they are captured by forecasted oil prices, and energy intensity in the Canadian manufacturing sector by controlling for autonomous energy-efficiency improvements and substitution effects captured by actual relative factor prices such that the estimated coefficients on forecasted energy prices provide information on price-induced energy efficiency improvements.

Finally, we have studied the implications of the "shale gas revolution" for Alberta climate change strategy to which CCS subsidy is a central approach. Alberta's 2008 Climate Change Strategy highlights the large greenhouse gas emission reduction potentials associated with Carbon Capture and Storage (CCS) technologies. To this effect, the government has allocated significant amounts of money to subsidize adoption of these technologies, and the Alberta CCS Development council recommends continuous provision of public subsidy. Meanwhile, the "shale gas revolution" has resulted in a significant increase in the supply of natural gas in North America, resulting in a significant drop in the price of natural gas. These dynamics were not in the picture when the Climate Change Strategy was prepared, as high natural gas price forecasts were used in the analysis that formed the basis for the strategy document. In the third study, we show that taking the new natural gas market realities into account significantly changes the potential role of CCS in the electricity sector. Using the CIMS simulation model, we show that coal plants equipped with CCS would not constitute a significant share of the market even when a 50% CCS subsidy is provided. Accordingly, the CO2 abatement potentials via CCS is limited. As a result, we conclude that justifying the huge CCS subsidies would be very difficult, at least for the electricity sector.

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APPENDICES

Appendix A

Chapter 2 Appendices

A.1 Capital Cost Calculations

Capital costs associated to the upgrade scenarios are computed using the information from Guler et al. (1999) and Aydinalp et al. (2001).

Costs of heating system upgrade:

These calculations are made for homeowners who were recommended to upgrade their furnace and domestic hot water heating system to medium or high efficiency models. Guel et al. (1999) provides corresponding retail purchase prices along with the removal and installation costs (Appendix Table A.1).

Some houses use a single natural gas or oil boiler to provide hot water for both space heat and DHW use. In these units, the total investment cost for an upgrade was evaluated as the installed cost of a space heating boiler alone, and the additional cost of connecting the DHW heating system was assumed to be negligible (Aydinalp et al., 2001).

Ceiling Insulation:

Following Aydinalp et al. (2001) ceiling upgrade costs are calculated using the following function:

$$CIIC = 1.65 + [0.93 \times (RSIU - RSI1)] \times area \qquad \text{(A.1)}$$

where CIIC is ceiling insulation investment cost; RSI is upgrade case RSI of ceiling insulation; where as RSI1 stands for the initial RSI; and Area

Table A.1: Cost Estimates for Space and Domestic Hot Water Heating Systems (Guler *et al.* 1999)

Space Heating Equipment	Efficiency(%)		Retail Cost ($)		Installation and Removal Cost($)
	Medium	High	Medium efficiency	High Efficiency	
Oil Furnace	80	87	1855	2164	499
Oil Boiler	80	87	2577	3608	400
Gas Furnace	80	92	1339	1964	800
Gas Boiler	80	88	1339	1964	800
	COP*		Installed Cost ($)		
Electric Air Source Heat Pump	2.19	2.34 - 2.6	4226	4536	
Domestic Hot Water Equipment	Efficiency(%)		Installed Cost ($)		
	Medium	High	Medium efficiency	High Efficiency	
Electric 60 Gallon	87	93	465	515	
Oil 60 Gallon	55	85	714	1161	
Gas 60 Gallon	55	65	485	515	

* COP is Coefficient of Performance, a measure of efficiency for heat pumps.

stands for total ceiling area, m^2.

Main Wall and Basement Wall Insulation:

Main wall insulation costs are calculated using the following function:

$$WIIC = C \times TMWA \qquad (A.2)$$

where WIIC stands for wall insulation investment costs, and TMWA stands for total main wall area, m^2; C = 17.2 for 2" x 4" construction and C = 19.4 for 2" x 6" construction. It was shown that that the building standards changed in 1977 such that all buildings before 1977 were of 2” x 4”construction while buildings constructed since 1977 are 2" x 6" construction. A rule of thumb was developed such that C = 17.2 is used for all houses with main wall RSI of less than 1.86 and C = 19.4 for main wall RSI including and greater than 1.86. Thus, if the upgrade case main wall insulation is 1.86 for example, we have WIIC = 17.2 x TMWA.

The cost function for basement wall insulation is given by a function similar to the wall insulation cost function except that, in this case, C = 21.73 for R -11 insulation and C = 23.59 for R -19 insulation, while TMWA now stands for total foundation wall area, m^2. It is shown that the C = 21.73 applies for RSI less than than 1.9 while C = 23.59 applies for RSI greater or equal to 1.9.

Information related to ceiling, main and basement wall areas are not provided in the EGH data available to the author. To overcome this, we consider that the amount of the heat loss through thermal envelopes depends both on the insulation and the area the need to be insulated. Thus, we multiply the unit costs by the recommended upgrade change in insulation (RSI) scaled by the ratio of the respective heat loss in total heating energy.

Of the upgrade types available, costs of upgrades such as caulking, weather striping, or any other upgrade leading to reduction in heat loss due to air leakage as well as window and door upgrades are not included.

Regional cost adjustments:

In order to account for regional variations, the adjustment factors provided by Gueler et al. (1999)(Appendix Table A.2) are applied. The costs are multiplied by the respective location factor to determine the cost in the region of interest. To account for the effect of local taxes on the retrofit cost, the regionally adjusted cost was also multiplied by the local tax rate.

Once the adjustment factors are applied to each cost estimate for all upgrade scenarios, we sum up them to arrive at total upgrade costs for each households who underwent first audit. It should be noted that our cost estimate is not comprehensive since we do not have information about the costs of the various window and door related upgrades.

Table A.2: Location factor and Tax adjustments for each province

	Location Factors (1)	Taxes (2)
Province	Repair and Remodeling	Combined rates
NFLD	0.96	1.150
PEI	0.92	1.177
NS	0.97	1.150
NB	0.93~0.96	1.150
QUE	1.01~1.03	1.150
ON	1.04~1.12	1.150
MAN	0.99	1.140
SAS	0.92	1.140
AB	0.99	1.070
BC	1.08~1.09	1.140

Source: Aydinalp et al. (2001)

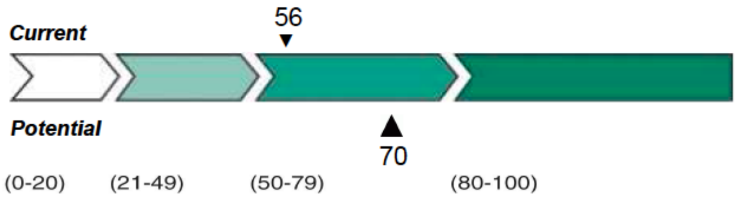
Figure A.1: **Sample EGH/ecoEnergy Retrofit Program Audit Report**

Energy Efficiency Evaluation Report

File number: 9906D02012

EnerGuide rating

Property Owner Name:



House type: detached

Year built: 1950

No. of storeys: 1

Sq. footage: 1905 ft.

No. of RO windows: 14
RO = rough opening

Air conditioner: yes

Main energy source: gas

Heating system: furnace

Domestic hot water: natural gas

Air leakage rate @ 50 Pa: 6.5ACH
ACH = number of air changes per hour

Critical Month (total): 0.26ACH

Equivalent Leakage Area: 355 ELA
ELA = units in square inches

The results of your ecoENERGY pre-retrofit assessment indicate that your house rates 56 points on the EnerGuide scale. If you implement all of the recommendations in this report, you could reduce your energy consumption by up to 28% and increase your home's energy efficiency rating to 70 points. The average energy efficiency rating for a house of this age in Canada is 70; whereas the highest rating achieved by the most energy efficient houses in this category is X.

When you reduce the amount of energy used in your home, you also reduce the production of greenhouse gases (GHG) such as carbon dioxide. If you improve your house's energy efficiency to 70 points, you will reduce its GHG emissions by 3.5 tonnes per year.

Remember, you have up to 18 months from the date of this report to complete your renovations and qualify for an ecoENERGY Retrofit – Homes grant.

Note: If you notice any discrepancies with the description of your home above, contact your service organization immediately.

Service Organization: Company name
Telephone: (xxx) xxx-xxxx

Date of evaluation: day, month spelled out, year
Date of report: day, month spelled out, year

Certified Energy Advisor: Advisor name

Certified Energy Advisor Signature

HOT2000 V10.2

Figure A.2: Figure A.1 Continued

YOUR HOME ENERGY ACTION CHECKLIST

Below you will find your checklist of recommendations to improve the energy efficiency of your home. This table shows the grant amounts that you could receive as well as the potential for energy savings and EnerGuide rating improvement. Before you renovate, ask about the appropriate products and installation techniques and be sure that all work meets local building codes and by-laws.

For more information, read the 'Recommended Energy-Saving Measures' section of this report and the NRCan brochure entitled *Retrofit Your Home and Qualify for a Grant!* found in your ecoENERGY kit.

Recommendations **These upgrades qualify for an incentive (up to a maximum total incentive value of $5000):**	**Incentive**	**Potential for Energy Savings ***	**Potential Rating Improvement**
VENTILATION SYSTEM Install an HVI-certified heat recovery ventilator.	$300	☼☼	X points
COOLING SYSTEM (A/C) Replace with an ENERGY STAR® qualified A/C system.	$200	☼☼☼	X points
DOMESTIC HOT WATER SYSTEM (DHW) Install a CSA compliant solar DHW system.	$500	☼☼	X points
ATTIC INSULATION Increase the insulation value to RSI 7 (R-40).	$400	☼☼☼☼	X points
HEATING SYSTEM Replace gas furnace with a minimum 92% AFUE ENERGY STAR® qualified unit and a DC variable-speed motor.	$500	☼☼☼☼☼	X points
WINDOWS AND DOORS Replace selected windows and exterior doors with ENERGY STAR® qualified units for climate zone [B].	$420	☼☼☼	X points
AIR SEALING Air seal to meet a 5.9 ACH @ 50 Pa or less.	$150	☼☼☼	X points
WATER CONSERVATION Replace your toilet with a low-/dual-flush model that meets the required specifications.	$50	N/A	N/A

* One (1) star = lowest savings / five (5) stars = highest savings

Figure A.3: Figure A.1 Continued

THE ENERGUIDE RATING SYSTEM

The EnerGuide rating system is a standardized method of evaluation that lets homeowners compare their house's energy efficiency rating to similar sized houses in similar regions. The EnerGuide rating considers the house's estimated annual energy consumption based on an in-depth evaluation of the house's characteristics such as location, size, equipment and systems, insulation levels, air tightness, etc. In addition, standardized conditions are used when calculating the rating in order to compare the efficiency of one house to another. These conditions include: a complete air change approximately every three hours; four occupants; a fixed thermostat setting of 21°C; average hot water consumption of 224 litres per day; average electricity consumption of 24 kWh per day; and the regional weather data that is averaged over the last 30 years.

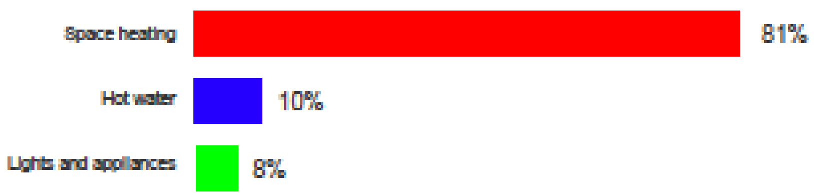
Figures 1 through 3 show the results of your energy evaluation based on the standardized conditions. The results may not entirely reflect your household since your actual energy consumption and future savings are influenced by the number of occupants, their day-to-day habits and lifestyles.

ENERGY CONSUMPTION

Houses lose heat to the outdoors during the heating season primarily through air leakage and conduction, such as the transfer of heat through the basement and exterior walls, ceilings, windows and doors (the 'building envelope'). Canada's demanding climate and modifications such as drilling holes in the building walls for new wiring, pipes and lights all play a part in reducing the efficiency of the building envelope over time. Houses need to be regularly maintained and upgraded to ensure greater energy efficiency, comfort and savings.

Figure 1 breaks down your house's estimated energy consumption for space heating, domestic hot water heating, and lights and appliances.

Figure 1. Energy Consumption Estimates



SPACE HEATING ANALYSIS

Figure 2 shows the estimated percentage of energy used for the space heating of your home.

- The top bar shows how much energy you would need for performing all of the upgrades recommended in this report, excluding changes to the space heating equipment. You could save up to 45 percent by performing all of the recommended non-space heating system upgrades.
- The bottom bar shows the potential space heating energy use if you were to implement all of the upgrades recommended in this report, including any space heating system upgrades. You could save up to 55 percent by performing all of the recommended upgrades.

Figure A.4: Figure A.1 Continued

Figure 2. Estimated Annual Space Heating Energy Consumption

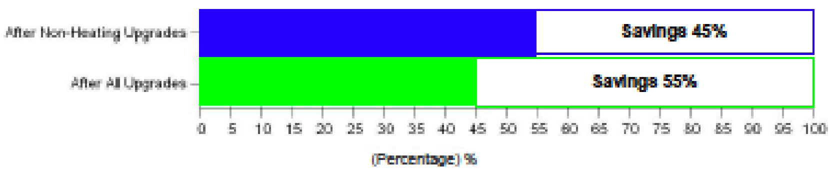
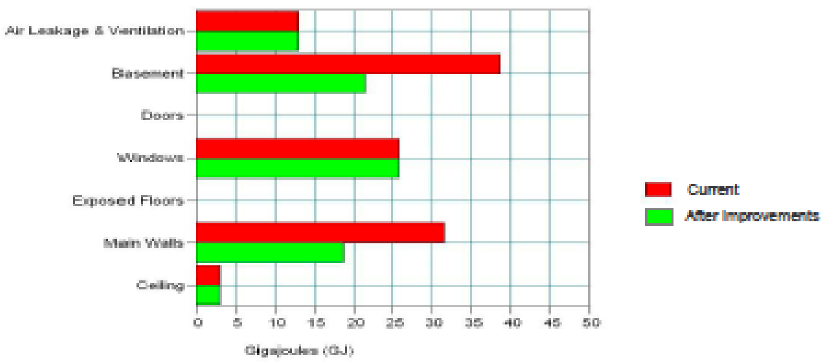


Figure 3 shows where the energy used for space heating actually gets lost in your home. This energy is measured in gigajoules (GJ), where 1 GJ is equivalent to 278 kilowatt-hours (kWh) or 948 MBtu/hour.

The red bars show the areas of your home where you are losing energy now. The longer the bar, the more energy you are losing. The green bars show the difference in energy loss after you complete your renovations. The larger the difference between the red and the green bars, the greater the potential for energy savings and comfort improvements.

Figure 3. Estimated Annual Heat Loss



Important Considerations:

When you decide to replace your heating system, make sure that your heating contractor performs a heat loss calculation on your home prior to installing the heating equipment. This will ensure that the new system has the correct capacity to heat your home. To get the most out of your retrofit, complete the other energy efficiency upgrades recommended in this report before having your heating system replaced, these upgrades can significantly reduce your home's heating needs and allow you to install a smaller and less costly system. Grossly oversized heating equipment costs more, takes up more floor space, operates less efficiently and tends to make the house less comfortable.

Figure A.5: Figure A.1 Continued

RECOMMENDED ENERGY-SAVING MEASURES

1. VENTILATION SYSTEM

Wind and temperature differences between the inside and outside of a house greatly affect the flow of air through the building envelope. That flow of air can cause both drafts and a lack of ventilation in areas of the house where it is most needed. It is best to seal the house as tightly as possible and then add a mechanical ventilation system (i.e., which acts as the lungs of the house) to maintain appropriate ventilation levels throughout the home.

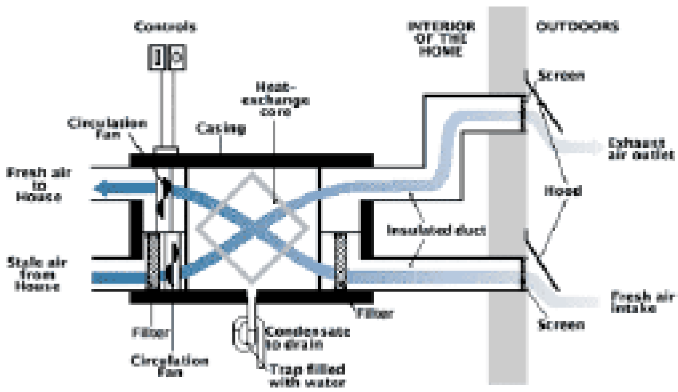
Total house ventilation helps remove or dilute the many sources of indoor air pollution coming from furnishings, cleaning products, pets, cooking, smoking etc. Exhaust-only fans that are vented outdoors, such as range hoods and bathroom fans, can reduce localized pollutants but only in rare cases do they perform efficiently enough to maintain adequate air quality in the home. Some indicators of potential indoor air quality problems are a build-up of condensation on windows, static shocks, mold growth and stale air (e.g., lingering cooking odours).

Your Home's Ventilation Rate

Ventilation rates are shown with a Critical Month (total). The Critical Month (total) is the sum of the *natural air changes per hour (ACH) rate* and the *exhaust flow rate* that comes from your home's existing ventilation equipment. The exhaust flow rate is a measure that uses the calendar month with the lowest natural ventilation rate (i.e., when the temperature difference between the inside and outside of the house is similar, thereby reducing the amount of natural ventilation). This critical month (total) is used to define the ventilation requirements of your home.

Your ventilation rate is greater than 0.2 ACH. At a minimum, energy-efficient and properly-vented exhaust fan(s) should be used between October and April. This practice helps to maintain good indoor air quality when natural air infiltration in and out of the home is reduced and when it is not practical to open windows. Refer to chapter 8 of the NRCan publication entitled *Keeping the Heat In* for additional information.

Recommendation of a Heat Recovery Ventilator (HRV)



Besides exhaust only fans, balanced ventilation from an energy efficient heat recovery ventilator is one of the best ways to control indoor air quality. An HRV reduces the cost of ventilation by recovering most of the heat from the exhausted air. The principle is simple: stale indoor air is drawn into the HRV and passed through a heat exchanger. The exchanger captures most of the heat before the stale air is exhausted to the outdoors. At the same time, outdoor air is drawn into the HRV, filtered and then passed through the other half of the heat exchanger. As it passes through the exchanger, it collects the heat from the exhausted air before being distributed throughout the house. Two common methods to distribute the warmed ventilation air are through an existing forced air distribution system or a dedicated ductwork system.

Figure A.6: Figure A.1 Continued

The installation of a new or more efficient Heating and Ventilation Institute (HVI)-certified HRV is eligible for an ecoENERGY Retrofit – Homes grant. It is highly recommended that all ventilation systems be designed and installed by a certified installer with the Heating, Refrigeration and Air Conditioning Institute of Canada (www.hrai.ca or 1-800-267-2231), in Quebec CMMTQ (www.cmmtq.org or 1-800-465-2668) or in B.C. TECA (www.teca.ca or 1-888-577-3818). For more information on HRVs, their maintenance and the need to ventilate a home, refer to the NRCan publication entitled *Heat Recovery Ventilator*.

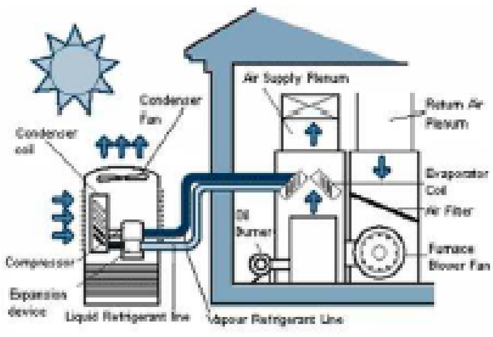
2. COOLING SYSTEM (A/C)

In summer, high relative humidity, elevated air temperatures and bright sunshine can produce an uncomfortable indoor environment. Air conditioning can provide comfort for occupants by lowering both the air temperature and also very importantly, the humidity level in the home.

All air conditioners should be serviced regularly as they can become inefficient when dirty or when the refrigerant runs low. Refrigerant lines should also be replaced to reduce the great risk of damage to the system from contamination of old refrigerants. Check your owner's manual for maintaining your air conditioning system and for more information on air conditioners, refer to the NRCan publication entitled *Air Conditioning Your Home*.

Split System Air Conditioner

Your central air conditioner is a split system, which means it has both an outside and inside component. The outside component is the condenser coil and the inside, the evaporator coil. Replacing your split system air conditioner with an ENERGY STAR® qualified condenser and evaporator coil of SEER 14 will improve your home's energy efficiency.



The evaporator coil is typically hidden in the plenum that is attached to the furnace and refrigerant tubing connects the two cooling components. The furnace blower fan circulates the cooled air throughout the home via the heating ducts.

Just like heating systems, cooling systems should be sized after all other energy efficiency renovations are completed. A properly sized cooling system will reduce cycling and remove more humidity from the air more effectively. Sizing of central AC systems should be determined by a licensed heating contractor who holds certification for Heat Loss/Heat Gain Calculations from the HRAI (www.hrai.ca or 1-800-267-2231), TECA (www.teca.ca or 1-888-577-3818) in B.C. or CMMTQ in Quebec (www.cmmtq.org or 1-800-465-2668).

ENERGY STAR® qualified AC systems use up to 20% less energy than standard new central air conditioners. **To ensure maximum specified efficiency and uncompromised longevity of the new system, the replacement of the matched indoor and outdoor units is critical and mandatory.** The same manufacturer's matched condenser unit and evaporator coil **must** be SEER 14 or greater to be eligible.

Figure A.7: Figure A.1 Continued

3. DOMESTIC HOT WATER SYSTEM (DHW)

Did you know that domestic water heating is the second-largest user of energy in most Canadian homes after space heating? On average, DHW systems account for 20% of the total annual energy consumption. Part of the consumption is a result of direct heat loss associated with *standby* and *wasted* water loss. Heat loss from tank-type water heaters, referred to as standby loss, occurs when heat is lost up its chimney, through the tank walls and through the water piping. Standby losses can be minimized by installing more energy efficient DHW systems that incorporate better burners and venting systems and higher insulation levels. In addition to DHW systems, there are other more simple measures that can be taken around the home to further reduce wasted heat loss from water usage. Fixing any dripping taps, washing laundry with cold water, insulating metallic hot water pipes and installing both low-flow showerheads rated at less than 9.5 litres per minute and faucet aerators also save on energy use.

By insulating the first two metres of your hot and cold metal water pipes with pipe insulation, you will not only save on your water heating costs, the amount of water you use will be reduced. Besides saving energy, water will arrive at the faucets closer to the desired temperature (e.g., warmer or colder) so your taps won't have to run as long. Insulating cold water pipes will also reduce condensation on the pipes that can lead to water stains on the surrounding areas. Note: for fuel-fired water heaters, maintain a 15-centimetre (6-inch) clearance between the pipe insulation and the vent pipe.

Fuel-fired DHW tanks and instantaneous equipment are rated with an energy factor (EF) or thermal efficiency (ET), and electric DHW equipment is rated in Watts of standby loss. The EF and ET measures the seasonal performance of water heaters – the higher the number, the better the efficiency. For electric heaters, the lower the Watts of standby loss, the higher the efficiency.

Note: there is no ENERGY STAR® qualified DHW equipment; however, high efficiency condensing gas-fired DHW equipment is available and is eligible for an ecoENERGY Retrofit – Homes grant. For more information on domestic water heaters, refer to NRCan's publications entitled: *Heating with Gas*; *Heating with Electricity*; and *Heating with Oil*.

Recommendation to Install a Solar Water Heater

The installation of a solar water heater will reduce your hot water heating costs and energy use. There are several factors involved when installing a solar water heating system: the size of the collectors, storage tank type, size and efficiency, amount of sunlight in your region and, very importantly, the amount of water you use. The following should be considered when installing your solar hot water heater: good sun orientation for panels (best orientation would be south, south-west or south-east), low shading (caused by proximity of other buildings and trees). A typical well designed solar hot water system can reduce annual hot water heating costs by as much as 50 percent (by providing 1500 to 3000 kWh of energy per year).

For more information, contact the Canadian Solar Industry Association (CANSIA) for a list of installers and dealers (www.cansia.ca or 613-736-9077). Solar collectors need to meet the standard CAN/CSA-F378-87 Solar Collectors to be eligible under ecoENERGY Retrofit –Homes. Refer to the "Glazed Water Heating Solar Collectors – Flat Plate Collectors" and "Glazed Water Heating Solar Collectors – Evacuated Tube Collectors" information in the ecoENERGY for Renewable Heat section of the Government of Canada's ecoACTION website (www.ecoaction.gc.ca).

Figure A.8: Figure A.1 Continued

4. ATTIC INSULATION

Insulation is manufactured, labeled and sold by its thermal resistance value (called the 'RSI' or 'R'-value) – a measurement of the insulation's resistance to heat flow. RSI is a metric unit whereas R-values are imperial (RSI 1 = R-5.678). The higher the RSI/R-value, the more efficient the insulation is.

The way the insulation is installed plays a significant role in its effectiveness. Compressing the insulation, leaving air spaces around it and allowing air movement through the insulation all reduce the actual RSI/R-value of the insulation.

Recommendation for Open Attic
Increasing the insulation levels in your attic to reach a minimum of RSI 7 (R-40) is recommended for your home.

Effective insulation systems slow the movement of heat and air and reduce chances of moisture accumulation. The following are important points that should be considered when upgrading your attic insulation:

- Perform air sealing measures to prevent the movement of air from the interior space into the attic space. Seal air leakage gaps around ceiling light fixtures, plumbing stacks, wiring and chimneys, and where possible, the tops of interior walls.
- Apply insulation uniformly in the attic and thermal bridging of the ceiling joists to help reduce heat loss. Joists are the structural part of the ceiling and are made of solid material with a lower R-value than the insulation. Thermal bridging allows a greater rate of heat transfer.
- Insulate all cavities to ensure no gaps are left.
- Avoid compressing the insulation.
- Ensure that soffit venting is not blocked by the added insulation. If so, baffles may have to be installed.
- Weatherstrip around the attic hatch or access.

Different materials can be used to insulate your attic. Some examples include blown-in cellulose and glass fibre, glass and mineral fibre, batt insulation and spray-on foam. For more information about installation methods, insulation values and properties, consult chapters 1 through 4 of NRCan's publication entitled *Keeping the Heat In* and Canada Mortgage and Housing Corporation's *About Your House* and *Renovating for Energy Savings* series of fact sheets.

5. HEATING SYSTEM

When replacing your heating system, your heating contractor should perform a heat loss calculation on your home to determine the capacity and distribution flows (air or water) for the new heating equipment. Your best option is to deal with a licensed heating contractor who holds certification for Heat Loss/Heat Gain Calculations from HRAI (www.hrai.ca or 1-800-267-2231), TECA (www.teca.ca or 1-888-577-3818) in B.C. or CMMTQ in Quebec (www.cmmtq.org or 1-800-465-2668).

It's important to complete the other non-heating recommended energy efficiency upgrades before you replace the heating system since proper sizing can result in smaller and less costly equipment. This helps to minimize efficiency losses and potential discomfort caused by oversized equipment.

If possible, heating equipment should be directly connected to an outdoor air supply to provide some air to the equipment for proper combustion. This connection helps to ensure no combustion gases leak into the home

Figure A.9: Figure A.1 Continued

should the house come under strong negative pressure (depressurization), such as when powerful ventilation fans are in use. An alternate option is to install a motorized combustion air damper on the outdoor air supply duct. This damper ensures combustion air is only supplied when required. During the summer, the damper stays closed and prevents humid outdoor air from coming in the house. In winter, the damper also stays closed when your heating equipment is not on, keeping unwanted cold air from entering the house unnecessarily.

High-efficiency heating equipment with direct sidewall venting of its combustion gases may require that the existing chimney be capped or relined. Relining allows for adequate air for the remaining systems that are using the existing chimney (e.g., hot water heater). However, it may not be possible to install some types of sidewall vented high efficiency heating equipment because of the location of the mechanical room or if there is no safe place to exhaust combustion gases on the side of your building.

Forced Air Furnace Recommendation

The replacement of your heating system with an ENERGY STAR® qualified gas furnace that has an AFUE of 90% or higher is recommended for your home. A new furnace will provide quick heat and filtered air while it can also be used to humidify, ventilate and cool your home. This type of equipment responds well to thermostat set-back (manual or automatic) as a simple way to save energy. Every degree Celsius of set back overnight and when away during the day saves approximately 2% in energy consumption.

High efficiency gas furnaces condense the water vapour from the combustion gases which increases their efficiency. They do however require a floor drain or optional pump to remove the collected water.

Before installing a new gas furnace and especially if installing a new central air conditioner, ensure that ductwork from the furnace is adequately sized and sealed, the supply and return flows are balanced and return air grills are also adequately sized and properly located (especially on upper floors). Oversized furnaces can give short bursts of hot air that can quickly heat the core of the home while leaving rooms further away under heated. When ductwork is properly installed, the flow of air is more consistent throughout the home, making it more comfortable to live in.

Direct Current (DC) Variable-Speed Motor

When operating the furnace blower fan for long periods of time such as when operating a central air conditioner, an air filtration system, a heat recovery ventilator or just for circulating the air continuously, a DC variable-speed motor has a typical payback period of just a couple of years.

Remember to have your furnace undergo regular maintenance so that it performs at its maximum efficiency. Clean or replace your air filter regularly and purchase only those that are properly sized to fit tightly in their frame.

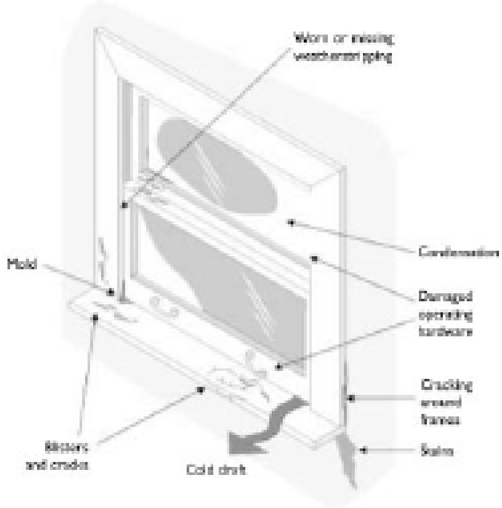
ENERGY STAR® Qualified Furnaces

Always consider ENERGY STAR® qualified furnaces as they ensure higher efficiencies and are eligible for ecoENERGY Retrofit – Homes grants. Note that the grant amounts differ based on their efficiency levels and the presence of an energy-efficient direct current (DC) variable-speed motor (refer to the NRCan publication entitled *Retrofit Your Home and Qualify for a Grant!*).

For more information on ENERGY STAR®, go to www.energystar.gc.ca or call 1-800-387-2000. For more information on heating systems, refer to NRCan's publications entitled *Heating with Gas*, *Choose the Right Condensing Gas Furnace*, *Heating with Electricity*, *Heating with Oil* or *Heating and Cooling with a Heat Pump*.

Figure A.10: Figure A.1 Continued

6. WINDOWS AND DOORS



A typical window will last twenty years or more so your selection of windows can help define energy efficiency and comfort levels in your home for years to come. Technical breakthroughs such as low-E coatings, triple glazing, inert gas fills, and better edge spacers and frames have improved window technology immensely, offering significant improvements in solar control, thermal comfort and energy efficiency.

Recommendation

The replacement of your windows with ENERGY STAR® qualified windows is recommended to improve the energy efficiency of your home. When replacing your windows, make sure that all models you select are matched to your climate zone (refer to 'Your Home Energy Action Checklist' on page 2 of your report for your climate zone). Under ecoENERGY Retrofit – Homes, a window is defined as the rough opening (RO) in the wall. The RO is the same as the opening left behind when the entire window unit is removed.

For information on purchasing energy-efficient windows, refer to NRCan's publication entitled *Consumer's Guide to Buying Energy-Efficient Windows and Doors*. For information on ENERGY STAR® qualified windows, doors and skylights, go to www.energystar.gc.ca.

7. AIR SEALING

The blower door test provides information about the air tightness of your home. There are three types of calculations from the blower door test: the number of complete air changes per hour (ACH), the critical month (total), and the equivalent air leakage area (ELA), all of which are noted on the first page of your report.

1. The ACH is a standard measure of the rate of air leakage that occurs when a *simulated pressure* difference between the inside and outside of the home is set at 50 Pascals (Pa). A 50 Pa pressure difference between the inside and outside of the home is the simulation of a wind blowing on your home at 56 kilometres per hour (or 35 miles per hour).

2. The Critical Month (total) is the sum of the *natural air change* rate and the *exhaust flow rate* generated by any existing ventilation equipment and is also measured in the number of air changes per hour (ACH). If the Critical Month (total) ACH is less than 0.3 ACH, mechanical ventilation would be required in your home to reduce the potential for conditions such as stale air, high humidity levels, and condensation buildup on window frames. A natural air change rate over 0.5 is usually an indication that the house is drafty and has a large amount of uncontrolled air leakage, therefore resulting in unnecessary energy loss. NRCan suggests levels of around 0.30 ACH (natural and mechanical) as a good rate to maintain good indoor air quality in the home.

3. The Equivalent Air Leakage Area (ELA). The ELA represents the sum of all air leakage areas in the building envelope of the home, in square inches. The larger the ELA, the leakier the house is. An energy-

Figure A.11: Figure A.1 Continued

efficient house might have an ELA as low as 40 square inches (sq. in.), while a leaky house may have an ELA of more than 500 sq. in.

Recommendations
Air leakage areas found in your house affect the overall amount of energy used to heat and cool your home. The following are the air leakage areas that were discovered during the blower door test:

☐ electrical outlets

☐ electrical ceiling fixtures

☐ electrical box and wire penetration

☐ exterior pipe penetration

☐ baseboard trims

☐ window frames

☐ door frames

☐ mouldings

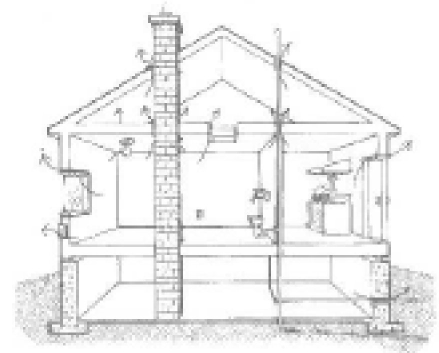
☐ fireplace

☐ chimney

☐ attic hatch

☐ basement header (rim joists)

☐ other ____________________



Typical leakage areas

Air Sealing Options
Weatherstripping is an inexpensive and important detail of the air sealing process. It can be used to air seal the gaps that can occur around windows and doors. It comes in various shapes, lengths, sizes and qualities. When installed correctly, it is an effective product that can reduce air leakage.

Caulking is another way to air seal small cracks and penetrations on the inside surface of your walls, ceilings and floors. There are two main types of caulking: for interior air sealing and the other for exterior air sealing. Interior air sealing prevents air from escaping into hidden cavities such as walls and roof, whereas exterior sealing keeps weather elements such as rain, snow, wind, as well as insects and rodents out!

You may decide to do the air-sealing job yourself if you have the time, patience and skills and are conscientious about air sealing in areas that can be difficult and uncomfortable to work in (e.g., the attic). However, professional air sealers can usually do a much better job because of their experience in locating and sealing leaks. Professional whole-house air sealing costs vary depending on the size and complexity of the house and work required. If you hire a contractor to do the work, the contract should specify each area to be sealed and the materials to be used and when possible, the performance level to be attained.

For information on improving the airtightness of your home, refer to chapter 3 of NRCan's publication entitled *Keeping the Heat In* and the publications entitled *Air Leakage Control* and *Improving Window Energy Efficiency*.

Figure A.12: Figure A.1 Continued

8. WATER CONSERVATION

Water conservation is an important part of a home energy saving plan. Whether you are on municipal water or a well, water savings can lessen your impact on the environment and can reduce costs associated with water treatment and delivery. Toilet usage can account for approximately 30 percent of indoor water use.

The amount of water you save depends on the flush volume of the toilet, how often the toilet is flushed and its condition (e.g., adding dye to the toilet tank water can reveal a leaky flush valve if the colour shows up in the bowl without flushing). For example, if you are replacing a toilet that commonly flushes with 13 litres of water with a new 6-litre model, you will save more than half of the water you and your family normally use. Additional water economy can be achieved by installing a dual-flush toilet as dual-flush toilets can save about 25 percent more water than a 6-litre toilet.

Recommendation
When replacing your toilet(s), purchase a toilet that will save on your water consumption. To be eligible for a grant under ecoENERGY Retrofit – Homes, new toilets must meet certain performance criteria for water savings sustainability and long-term water saving performance. Information on qualified makes and models is available at www.veritec.ca. Note: you must keep sufficient documentation on the make and model number of the replacement model to ensure compliance.

Here are the requirements for the toilets.

Low-flush or dual-flush models must be:
1. rated at 6 litres per flush or less;
2. meet the Los Angeles Supplementary Purchase Specification (shown as SPS on the list); and
3. have a flush performance of 350 grams or more.

Appendix B

Chapter 3 Appendices

B.1 Trends in Shares of industry groups (composition of the manufacturing sector)

B.2 Aggregation of Energy Intensity

Alternatively, we can apply the Divisia index approach and apply the log-mean weights following Ang (2005). To observe how this goes, define that an energy intensity of an industry group is $EI_{gt} = \sum_{i\epsilon g} EI_{it}$ where EI_{it} is trends in energy intensity of sub-group (industry) i. Let $E_{it}$and Y_{it} denote energy use and GDP in sub-group i, respectively, and Y_t denote the sum of Y_{it}. Then, we define energy intensity of an industry group as:

$$EI_{gt} = \sum_{i\in g}\left(\frac{Y_{it}}{Y_{gt}}\frac{E_{it}}{Y_{it}}\right) = \sum_{i\in g} s_{it}\frac{E_{it}}{Y_{it}} = \sum_{i\in g} s_{it}EI_{it}. \tag{B.1}$$

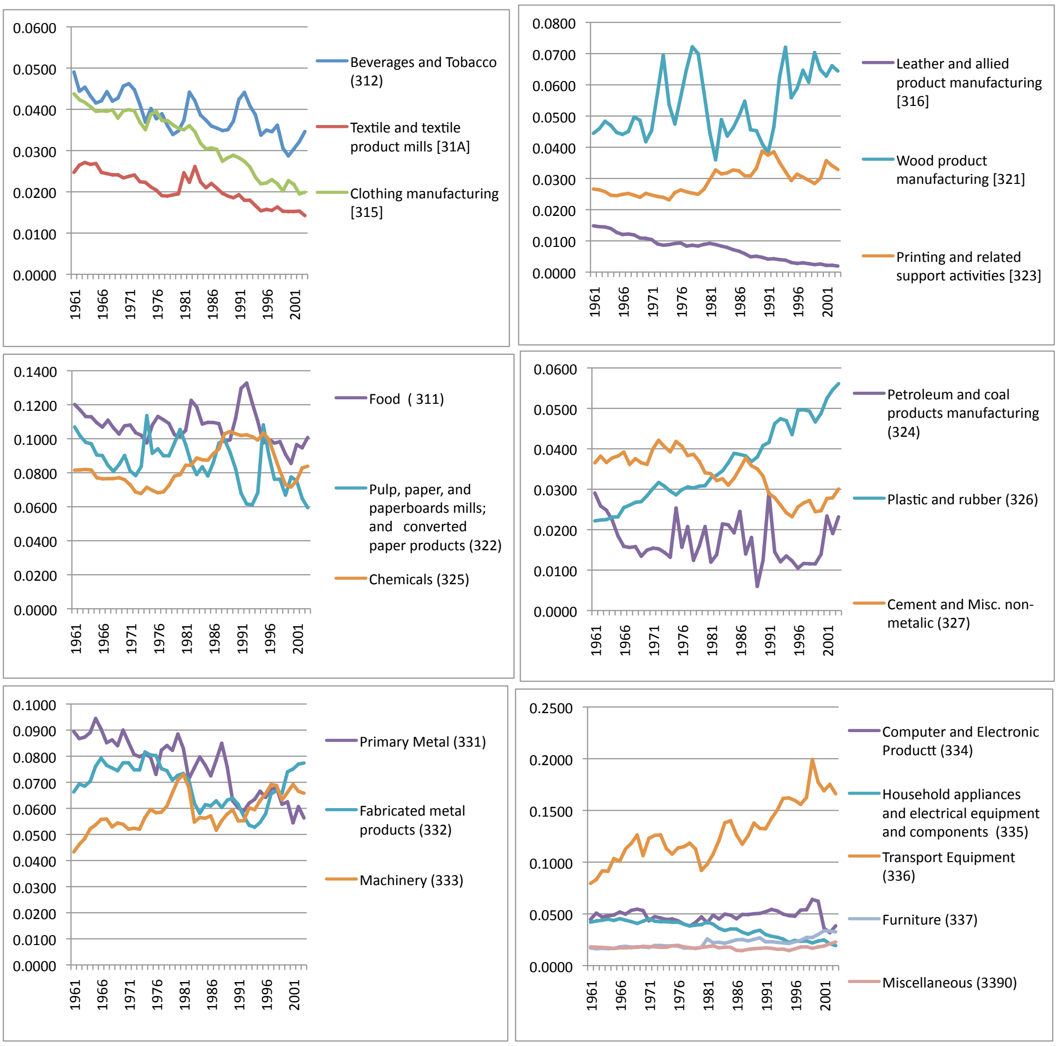
That is, changes in energy intensity of an industry group results from changes in both the structure (s_{it}) and the energy intensity within a sub-group $\left(\frac{E_{it}}{Y_{it}}\right)$. Differentiating both sides with respect to time gives us:

$$\frac{dEI_{gt}}{dt} = \sum_{i\in g} s_{it}\frac{dEI_t}{dt} + \sum_{i\in g} EI_{it}\frac{dS_{it}}{dt}. \tag{B.2}$$

and dividing both sides by $EI_{gt} = \sum_{i\in g} s_{it}EI_{it}$ gives us:

$$\frac{1}{EI_{gt}}\frac{dEI_{gt}}{dt} = \sum_{i\in g}\frac{s_{it}}{\sum_{i\in g} s_{it}EI_{it}}\frac{dEI_{it}}{dt} + \sum_{i\in g}\frac{EI_{it}}{\sum_{i\in g} s_{it}EI_{it}}\frac{ds_{it}}{dt} \tag{B.3}$$

Figure B.1: Trends in Shares of industry groups (composition of the manufacturing sector)



Multiplying both the numerators and the denominators of the first right hand side terms by EI_{it} and the second term by s_{it} gives us:

$$\frac{1}{EI_{gt}}\frac{dEI_{gt}}{dt} = \sum_{i\in g}\frac{s_{it}EI_{it}}{\sum_{i\in g}s_{it}EI_{it}}\frac{dEI_{it}}{EI_{it}dt} + \sum_{i\in g}\frac{s_{it}EI_{it}}{\sum_{i\in g}s_{it}EI_{it}}\frac{ds_{it}}{s_{it}dt} \tag{B.4}$$

Noting that $s_{it}EI_{it} = \frac{Y_{it}}{Y_{gt}}\frac{E_{it}}{Y_{it}}$ and $\sum_{i\in g}s_{it}EI_{it} = EI_{gt} = \frac{E_{gt}}{Y_{gt}}$. Thus,

$$\frac{s_{it}EI_{it}}{\sum_{i\in g}s_{it}EI_{it}} = \frac{Y_{it}}{Y_{gt}}\frac{E_{it}}{Y_{it}}\Big/\frac{E_{gt}}{Y_{gt}} = \frac{E_{it}}{E_{gt}}. \tag{B.5}$$

That is, the relevant weight is the share of energy use by each subgroup. Denoting $\frac{E_{it}}{E_{gt}}$ by w_{it} gives us:

$$\frac{1}{EI_{gt}}\frac{dEI_{gt}}{dt} = \sum_{i\in g}w_{it}\frac{dEI_{it}}{E_{it}dt} + \sum_{i\in g}w_{it}\frac{ds_{it}}{s_{it}dt} \tag{B.6}$$

This equation can be re-written as:

$$\frac{dln(EI_{gt})}{dt} = \sum_{i\in g}w_{it}\frac{dln(EI_{it})}{dt} + \sum_{i\in g}w_{it}\frac{dln(s_{it})}{dt} \tag{B.7}$$

Noting that actual data is available in discrete time, discrete integration is used to re-write the equation as:

$$ln\left(\frac{EI_{gt}}{E_{g0}}\right) = \sum_{i\in g}w_{it}ln\left(\frac{EI_{it}}{EI_{i0}}\right) + \sum_{i\in g}w_{it}ln\left(\frac{s_{it}}{s_{i0}}\right) \tag{B.8}$$

or

$$\begin{aligned}\frac{EI_{gt}}{E_{g0}} &= \exp\left\{\sum_{i\in g}w_{it}ln\left(\frac{EI_{it}}{EI_{i0}}\right) + \sum_{i\in g}w_{it}ln\left(\frac{s_{it}}{s_{i0}}\right)\right\}\\ &= \exp\left\{\sum_{i\in g}w_{it}ln\left(\frac{EI_{it}}{EI_{i0}}\right)\right\}\bullet\exp\left\{\sum_{i\in g}w_{it}ln\left(\frac{s_{it}}{s_{i0}}\right)\right\}\end{aligned} \tag{B.9}$$

where 0 denotes base year. Keeping s_{it} at base year value, as well as using $EI_{g0} = 1$ and $EI_{i0} = 1$ as in index numbers gives us:

$$EI_{gt} = \exp\left\{\sum_{i \in g} w_{it} lnEI_{it}\right\} \tag{B.10}$$

This equation represents intensity index in group g. The weight function is traditionally approximated by the arithmetic mean of the base year and current year weights. This, however, leaves small residue. Ang (2005) proposes the log-mean approach:

$$L(w_{i0}, w_{it}) = \frac{w_{it} - w_{i0}}{ln(\frac{w_{it}}{w_{i0}})} \tag{B.11}$$

Since this does not add up to unity, however, a normalized weight is computed as:

$$w_{it}^{*} = \frac{L(w_{io}, w_{it})}{\sum_{i \in g} L(w_{i0}, w_{it})} \tag{B.12}$$

so that a group's energy intensity (in natural logarithm) is given by:

$$EI_{gt} = \exp\left\{\sum_{i \in g} w_{it}^{*} lnEI_{it}\right\} \tag{B.13}$$

Table B.1: Summary of Manufacturing Sector Energy End-Use and Intensity, 1990–2007

	(1) Total Fuel (TJ)	(2) Growth in Fuel Use (%)	(3) Gross Output (in 1997 Million Dollar)	(4) Energy (TJ) / Output	(5) Growth rate in TJ/Output (%)	(6) Total (TJ) - percent of total	(7) Gross Output - percent of total	(8) Energy (TJ) / Output - ratio of total	(9) Share of Non-elecric fuel (%)
All Manufacturing Industries - excluding mining	2452032	0.13	505470.50	4.98	-2.27	100	100	1.00	74
Food	88928.9	1.27	61529.44	1.46	-0.73	3.63	12.17	0.29	76
Beverage and Tobacco	12827	-0.22	12727.56	1.01	-0.40	0.52	2.52	0.20	80
Textile Mills	11835	-2.88	3203.83	4.23	-4.19	0.48	0.63	0.85	67
Textile Product	5655	-3.89	2468.89	2.60	-5.82	0.23	0.49	0.52	68
Clothing	4512	-6.14	7207.61	0.63	-5.83	0.18	1.43	0.13	55
Leather and Allied Product	954	-7.45	751.44	1.25	-4.85	0.04	0.15	0.25	57
Wood Product	106696	6.12	29426.17	3.56	3.30	4.35	5.82	0.71	74
Pulp and Paper	812986	-1.08	32377.06	25.41	-2.73	33.16	6.49	5.12	76
Printing and Related Support Activities	8500	1.42	11058.28	0.74	-2.07	0.26	2.18	0.12	56
Petroleum and Coal Products	334005	1.05	30819.22	10.92	-0.85	13.64	6.15	2.23	94
Chemical Manufacturing	270142.7	0.04	39019.72	7.10	-2.04	11.02	7.74	1.43	73
Plastics and Rubber Products	29950.33	3.08	21305.56	1.41	0.26	1.22	4.19	0.29	52
Non-Metallic Mineral Product	121156.0	-6.72	10524.39	11.80	-2.37	4.94	2.09	2.38	87
Primary Metals Manufacturing	509361.8	0.93	31843.39	16.33	-1.66	20.79	6.32	3.29	57
Fabricated Metal Product	36620.39	1.48	27897.83	1.33	-0.96	1.49	5.52	0.27	72
Machinery	14343.67	2.87	24029.83	0.61	0.27	0.58	4.75	0.12	72
Computer and Electronic Product	5414.07	1.93	18728.39	0.29	-4.50	0.22	3.71	0.06	37
Electrical Equipment, Appliance and Component	7382.79	-0.42	8631.94	0.83	-2.19	0.23	1.71	0.14	67
Transportation Equipment Manufacturing	55208.17	0.56	112927.50	0.51	-2.23	2.25	22.34	0.10	68
Furniture and Related Product Manufacturing	8557.78	4.05	11069.17	0.78	-1.01	0.35	2.19	0.16	64
Miscellaneous	5732.17	2.55	7923.28	0.74	3.27	0.00	1.59	0.15	61
Standard Deviation	207244.2	3.6	25156.0	6.5	2.5	8.5	5.0	1.3	12.5

Source: Computed from CIEEDAC database; www.SFU.ca/CIEEDAC

Table B.2: Summary Statistics for variables used in Estimation

	Obs	Mean	Std. Deviation	Min.	Max		Mean	Std. Deviation	Min.	Max
All groups (Manufacturing)						**Food (311)**				
Energy Instensity	33	1.55	0.60	0.99	2.98		1.39	0.31	0.89	1.98
$(PK/PE)^{0.5}$	33	1.23	0.21	0.96	1.76		0.97	0.06	0.84	1.10
$(PL/PE)^{0.5}$	33	1.05	0.12	0.90	1.33		0.97	0.04	0.85	1.02
$(PM/PE)^{0.5}$	33	1.21	0.25	0.93	1.78		1.07	0.08	0.95	1.23
$(PS/PE)^{0.5}$	33	1.12	0.19	0.94	1.59		1.18	0.22	0.92	1.64
Beverages and Tobacco (312)						**Textile and textile product mills [31A]**				
Energy Instensity	33	1.36	0.41	0.77	2.42		1.59	0.52	0.92	2.70
$(PK/PE)^{0.5}$	33	0.96	0.15	0.77	1.37		0.93	0.13	0.71	1.26
$(PL/PE)^{0.5}$	33	1.08	0.11	0.93	1.29		1.07	0.14	0.90	1.42
$(PM/PE)^{0.5}$	33	1.11	0.19	0.95	1.54		1.28	0.30	0.93	1.97
$(PS/PE)^{0.5}$	33	1.06	0.16	0.86	1.44		1.11	0.20	0.91	1.61
Clothing manufacturing [315]						**Leather and allied product manufacturing [316]**				
Energy Instensity	33	1.79	0.57	0.96	2.87		3.33	2.11	0.89	7.76
$(PK/PE)^{0.5}$	33	1.10	0.11	0.92	1.32		1.17	0.21	0.84	1.68
$(PL/PE)^{0.5}$	33	0.93	0.08	0.80	1.06		1.14	0.20	0.95	1.65
$(PM/PE)^{0.5}$	33	1.22	0.25	0.94	1.78		1.06	0.14	0.90	1.38
$(PS/PE)^{0.5}$	33	1.14	0.19	0.97	1.57		1.12	0.21	0.93	1.63
Wood product manufacturing [321]						**Pulp, paper, and paperboards mills ... (322)**				
Energy Instensity	33	1.061	0.302	0.629	1.875		1.52	0.47	0.87	2.80
$(PK/PE)^{0.5}$	33	1.796	1.004	0.959	4.247		1.07	0.33	0.35	1.97
$(PL/PE)^{0.5}$	33	1.046	0.129	0.776	1.299		1.08	0.13	0.93	1.40
$(PM/PE)^{0.5}$	33	1.181	0.215	0.947	1.685		1.21	0.20	0.94	1.63
$(PS/PE)^{0.5}$	33	1.148	0.193	0.965	1.593		1.18	0.23	0.96	1.72
Printing and related support activities [323]						**Petroleum and coal products manufacturing (324)**				
Energy Instensity	33	0.94	0.18	0.62	1.35		0.46	0.25	0.15	1.10
$(PK/PE)^{0.5}$	33	0.87	0.09	0.67	1.07		0.60	0.21	0.08	1.11
$(PL/PE)^{0.5}$	33	1.12	0.15	0.94	1.44		0.91	0.12	0.58	1.14
$(PM/PE)^{0.5}$	33	1.17	0.20	0.93	1.63		0.87	0.09	0.72	1.07
$(PS/PE)^{0.5}$	33	1.12	0.17	0.94	1.52		0.99	0.13	0.81	1.30
Chemicals (325)						**Plastic and rubber (326)**				
Energy Instensity	33	1.22	0.21	0.84	1.59		0.97	0.13	0.76	1.28
$(PK/PE)^{0.5}$	33	1.02	0.17	0.71	1.34		0.94	0.23	0.56	1.55
$(PL/PE)^{0.5}$	33	1.06	0.13	0.90	1.37		1.05	0.12	0.91	1.33
$(PM/PE)^{0.5}$	33	1.14	0.17	0.95	1.50		1.15	0.18	0.95	1.59
$(PS/PE)^{0.5}$	33	1.11	0.19	0.91	1.59		1.07	0.18	0.87	1.49
Cement and Misc. non-metalic (327)						**Primary Metal (331)**				
Energy Instensity	33	1.82	0.78	0.94	3.34		1.70	0.51	0.91	2.46
$(PK/PE)^{0.5}$	33	0.95	0.19	0.57	1.38		1.62	0.77	0.98	3.62
$(PL/PE)^{0.5}$	33	1.06	0.13	0.90	1.37		0.97	0.09	0.82	1.13
$(PM/PE)^{0.5}$	33	1.19	0.20	0.95	1.66		1.13	0.15	0.96	1.52
$(PS/PE)^{0.5}$	33	1.11	0.18	0.91	1.57		0.98	0.12	0.83	1.31
Fabricated metal products (332)						**Machinery (333)**				
Energy Instensity	33	1.18	0.33	0.79	1.83		1.44	0.28	1.00	1.90
$(PK/PE)^{0.5}$	33	0.94	0.18	0.68	1.40		0.96	0.14	0.64	1.24
$(PL/PE)^{0.5}$	33	1.08	0.16	0.92	1.45		1.04	0.13	0.90	1.34
$(PM/PE)^{0.5}$	33	1.20	0.21	0.94	1.66		1.09	0.15	0.95	1.43
$(PS/PE)^{0.5}$	33	1.21	0.23	0.96	1.75		1.12	0.20	0.94	1.59
Computer and Electronic Product (334)						**Household appliances …. (335)**				
Energy Instensity	33	16.70	20.65	0.89	64.47		2.76	1.20	0.90	4.88
$(PK/PE)^{0.5}$	33	3.93	1.34	1.00	6.71		1.37	0.27	0.84	2.02
$(PL/PE)^{0.5}$	33	1.02	0.12	0.84	1.28		1.07	0.15	0.93	1.43
$(PM/PE)^{0.5}$	33	2.22	1.26	0.90	4.73		1.16	0.21	0.94	1.64
$(PS/PE)^{0.5}$	33	1.09	0.20	0.91	1.56		1.12	0.19	0.95	1.59
Transport Equipment (336)						**Furniture (337)**				
Energy Instensity	33	1.35	0.35	0.93	2.30		1.00	0.13	0.72	1.25
$(PK/PE)^{0.5}$	33	0.97	0.20	0.66	1.46		0.86	0.12	0.63	1.16
$(PL/PE)^{0.5}$	33	1.03	0.12	0.86	1.30		1.04	0.13	0.89	1.34
$(PM/PE)^{0.5}$	33	1.11	0.17	0.92	1.50		1.15	0.19	0.94	1.61
$(PS/PE)^{0.5}$	33	1.14	0.22	0.96	1.65		1.11	0.19	0.91	1.54
Average Forecast Price	33	0.91	0.17	0.62	1.27					
World Per Capita GDP	33	8.37	0.13	8.13	8.59					
World Oil Production	33	4.08	0.09	3.88	4.24					
TSX Composit Index	33	7.91	0.71	6.79	9.10					
Lending Interest rate	33	0.12	0.16	0.04	0.97					
Exchange rate	33	1.25	0.17	0.98	1.57					
Inflation	33	0.05	0.04	0.00	0.15					

Table B.3: Trends by Decade

	Average Energy Intensity					Average prices of Captial Servies				
Subsectors	1961-70	1971-80	1981-90	1990-03	1961-03	1961-70	1971 -80	1981-90	1990-03	1961-03
Food (311)	1.93	1.56	1.12	1.06	1.39	0.17	0.33	0.72	0.99	0.58
Beverages and Tobacco (312)	1.85	1.47	1.08	0.96	1.32	0.21	0.24	0.55	0.85	0.49
Textile and textile product mills [31A]	1.97	1.57	1.07	1.11	1.41	0.19	0.25	0.78	0.78	0.52
Clothing manufacturing [315]	1.40	1.30	1.04	1.12	1.21	0.25	0.54	1.05	1.22	0.80
Leather and allied product manufacturing [316]	1.69	1.46	0.97	1.04	1.27	1.24	1.58	2.95	1.12	1.68
Wood product manufacturing [321]	1.60	1.59	1.16	1.08	1.34	0.06	0.17	0.17	0.72	0.31
Pulp, paper, and paperboards mills; and converted paper products (322)	1.43	1.52	1.07	1.02	1.24	0.27	0.54	0.89	0.92	0.67
Printing and related support activities [323]	1.30	1.12	0.92	1.13	1.12	0.05	0.13	0.43	0.60	0.32
Petroleum and coal products manufacturing (324)	0.18	0.31	0.44	0.82	0.46	0.12	0.11	0.25	0.56	0.28
Chemicals (325)	1.71	1.48	1.01	1.07	1.30	0.13	0.18	0.71	1.04	0.55
Plastic and rubber (326)	2.07	1.94	1.32	1.19	1.60	0.12	0.14	0.27	0.71	0.34
Cement and Misc. non-metalic (327)	2.37	2.02	1.39	1.18	1.70	0.14	0.29	0.61	0.70	0.45
Primary Metal (331)	1.54	1.73	1.26	1.16	1.40	0.21	0.26	0.47	0.66	0.42
Fabricated metal products (332)	1.96	1.62	1.13	1.25	1.47	0.11	0.22	0.35	0.64	0.35
Machinery (333)	2.39	2.03	1.46	1.37	1.78	0.10	0.22	0.41	0.76	0.40
Computer and Electronic Productt (334)	36.19	56.88	7.82	1.45	23.90	33.37	8.72	18.29	11.19	17.43
Household appliances and electrical equipment and components (335)	2.74	2.09	1.76	1.37	1.95	0.67	1.05	1.90	1.39	1.26
Transport Equipment. (336)	3.19	2.57	1.66	1.31	2.12	0.07	0.15	0.34	0.76	0.36
Furniture (337)	2.22	1.79	1.35	1.36	1.66	0.04	0.08	0.34	0.58	0.28
Miscellaneous (3390)	2.65	2.17	1.42	1.30	1.84	0.06	0.17	0.29	0.57	0.29
Aggregate Manufacturing	2.84	3.02	1.41	1.17	2.04	0.80	0.38	0.83	1.05	0.78