# ESTIMATING THE IMPACT OF BEHAVIOUR ALTERING TAXES ON HOUSEHOLD CONSUMPTION

By

Di Xiang

A Thesis Submitted to the Faculty of Graduate Studies of

The University of Manitoba

in Partial Fulfillment of the Requirements of the Degree of

**DOCTOR OF PHILOSOPHY**

Department of Economics

University of Manitoba

Winnipeg, Manitoba

| | |
|---|---|
| **DOCTOR OF PHILOSOPHY (2015)** | **University of Manitoba** |
| **(Economics)** | **Winnipeg, Manitoba** |

| | |
|---|---|
| **TITLE:** | Estimating the Impact of Behaviour Altering Taxes on Household Consumption |
| **AUTHOR:** | Di Xiang<br>B.A. -Economics, Honors (Shandong University)<br>M.Sc. - Agribusiness and Agricultural Economics<br>(University of Manitoba) |
| **SUPERVISORS:** | Dr. Chad Lawley (Supervisor)<br>Dr. Ryan Cardwell<br>Dr. Elizabeth Troutt |
| **NUMBER OF PAGES:** | v, 138 |

**ACKNOWLEDGEMENT**

It's my pleasure to thank those whose assistance, support and encouragement made this thesis possible. First, I would like to thank my husband Lue Zhan, for his unreserved support and understanding of my journey through the PhD process. Next, I am heartily thankful to my thesis advisor, Dr. Chad Lawley, for constant discussion, tremendous encouragement and invaluable guidance in my PhD study. Dr. Lawley not only aided me in improving my work, but also kept me moving ahead when I might otherwise have quit. I am grateful to Dr. Ryan Cardwell, for his time and effort in going through this thesis and research paper providing invaluable feedback that aided in improving the final version of this dissertation. I would like to thank Dr. Elizabeth Troutt for her encouragement and support in my study, her willingness to help in whatever capacity she could, and providing valuable feedback, which has clearly improved the end product. I am grateful to the external examiner, Dr. Joel Bruneau, for his time and effort in going through this thesis and providing invaluable feedback that aided in improving the final version of this dissertation. I would also like to express my thanks and appreciation to Dr. Soham Baksi, who gave me great suggestions and training in my research.

# ESTIMATING THE IMPACT OF BEHAVIOUR ALTERING TAXES ON HOUSEHOLD CONSUMPTION

## Table of Contents

# List of Tables and Figures

# CHAPTER 1

## An Introduction

People respond to incentives—people make decisions by comparing the costs and benefits of a particular action. When either the costs or benefits change, behaviour also changes. Evidence from economic research indicates that tax rates do influence individual behaviour when it comes to working, investing, saving, and entrepreneurship. In Canada and most countries, taxes are collected by different levels of government to fund their programs and services. There are different types of taxes applied by these levels of government on consumers, wage earners, and businesses. The basic types of taxes include: (1) taxes paid by the individual, such as income taxes, property taxes, and consumption (retail or sales taxes) and excise taxes; (2) taxes paid by businesses, such as corporate taxes and payroll taxes; and (3) other types of taxes such as capital gains taxes, and inheritance or estate taxes.

There are three goals of taxation. The primary goal of a tax system is to generate revenues to support government functions at all levels. Second, taxation can have a redistribution function, where reducing the unequal distribution of income/wealth generated from the normal operation of a market-based economy is thought to increase fairness. Third, taxation may have a regulatory function since it can be used to steer individual/business behaviour in the directions desired by governments (Avi-Yonah, 2006). In this dissertation, I focus on consumption taxes aimed at influencing individuals' activities and choices. Higher taxes may lead to lower rates of economic growth and reduced rates of personal income growth. However, a proper tax imposed to alter individuals' behaviour might positively affect the economy, either through improvements in public health or the environment.

In this dissertation, I examine how two taxes—a hypothetical "fat tax" and British Columbia's carbon tax—affect consumer behaviour. In the first essay I conduct an empirical examination of a hypothetical "fat tax" on household food consumption in Canada. This essay sheds light on the regressivity of fat taxes and potential adjustments that can be made to make the tax more progressive. I also examine the impact of various fat tax policies on nutrient intake in Canada.

Of the few studies that do exist, some have challenged the ability of fat taxes to significantly decrease calorie intake, since such a tax ignores the interdependence of food consumption choices—the possibility that consumers will substitute for other untaxed unhealthy food (Becker, 2009; Posner, 2009; Allais et al. 2011; Nordstrom et al. 2009 and 2011(b); Finkelstein et al. 2013). In addition, some studies find that a stand-alone fat tax is regressive, since it hurts lower income households (Chouinard et al. 2007; Zhen et al. 2010). However, there is little empirical work exploring more comprehensive tax reforms and redistribution, and their related impacts on household income and health. Thus, the first essay seeks to extend the range and scope of the literature by examining the impact of four food policies on household income and health, including (1) a stand-alone fat tax on sugar sweetened beverages (SSBs), sugar-fat products, salt-fat products, and prepared meals, (2) a stand-alone food subsidy on fruits and vegetables, (3) a revenue- neutral fat tax with a lump-sum transfer to households, and (4) a revenue- neutral fat tax combined with a subsidy to fruits and vegetables.

I estimate the parameters of an Exact Affine Stone Index (EASI) demand system (Lewbel and Pendakur, 2009), where a two-step estimation procedure is used to deal with censored food expenditures. Statistics Canada's Food Expenditure Survey (2001) and the Health Canada Commodity Nutrient File (2010) are used in the essay.

The simulation results suggest that the most efficient and progressive scenario from both economic and health perspectives is a fat tax with the revenue recycled as a lump-sum transfer to households.

The second and third essays attempt to shed some light on the impact of the BC carbon tax on residential/household natural gas consumption. The second essay investigates the impact of the tax on natural gas consumption from an aggregate perspective. Previous existing literature has explored the overall impact of the BC carbon tax on carbon-based fuel consumption and has found that the carbon tax effectively decreases greenhouse gas (GHG) emissions on a per capita basis (Elgie and McClay, 2013). Rivers and Schaufele (2013) find that the carbon tax is more salient in decreasing gasoline consumption than equivalent price changes (Rivers and Schaufele, 2013). There is little research addressing the impact of the carbon tax on residential natural gas consumption. The primary purpose of the second essay is to fill this gap in the literature.

I use a comparative case study approach, specifically the synthetic control method. The relevant investigation is based on panel data of 34 provinces/states in both Canada and the United States from 1990 to 2012. The essay reports that, though natural gas consumption did fall, the results from placebo tests suggest that the decline of natural gas consumption is insignificant. Several robustness checks support this result. Further, two regression analyses are conducted—a tax salience regression and a standard differences-in-differences regression. The results of the regression analyses are consistent with the estimation using the synthetic control approach. That is, using aggregate data, I find no significant impact of the BC carbon tax on residential natural gas consumption.

The third essay is a further investigation of the BC carbon tax on household natural gas consumption. It addresses two related questions. First, what is the overall impact of the BC carbon tax on residential natural gas use? Second, do "environmentalist" households reduce their residential energy use more or less than non-environmentalist households in response to a carbon tax?

Several studies have examined the role of demographics in residential energy use (Brounen, Kok, and Quigley, 2012; Maddala, Trost, Li and Joutz, 1997; Davis and Killian, 2011). However, they do not examine differential responses to green taxes. In addition, previous work has examined energy consumption varied by environmental ideology in the context of *voluntary* green "nudges" (Costa, and Kahn, 2013; Kotchen and Moore, 2007 and 2008). There is less research evaluating differential responses in the context of a *mandatory* tax. Thus, the third essay focuses on examining household responses to the carbon tax utilizing household-level data. Further, an investigation of heterogeneous responses to the carbon tax is conducted.

The results of the investigation suggest that there is little evidence that the carbon tax is more salient than equivalent price changes. Moreover, the results suggest that the impact of the carbon tax is more effective for non-environmentally conscious households than for other households. Based on the estimation, it is found that the carbon tax is more salient than equivalent market price changes in the non-environmentally conscious households, whereas the environmentally conscious households do not respond to the carbon tax. The possible explanation for that is the environmentally conscious households may already adopt a greener lifestyle by voluntarily restraining their household energy consumption. Therefore, a mandatory carbon tax which tries to influence consumption through price incentive may not affect the consumption of natural gas for environmentally conscious households.

**REFERENCES**

Avi-Yohna, Reuven S. 2006. The Three goals of Taxation. Tax Law Review. 60, No.1: 1-28

Brounen, D., N. Kok, and J.M. Quigley. 2012. Residential Energy Use and Conservation: Economics and Demographics. *European Economic Review* 56: 931-945.

Costa, D., and M. Kahn. 2013. Energy Conservation "Nudges" and Environmentalist Ideology: Evidence from a Randomized Residential Electricity Field Experiment. *Journal of the European Economic Association* 11(3): 680-702.

Elgie, S., and J. McClay. 2013. Policy Commentary: BC's Carbon Tax Shift is Working Well after Four Years. *Canadian Public Policy* 39(2): 1-10.

Kotchen, M. J. and M. R. Moore. 2007. Private Provision of Environmental Public Goods:

Household Participation in Green-Electricity Programs. *Journal of Environmental Economics and Management* 53, 1–16.

Kotchen, M. J. and M. R. Moore. 2008. Conservation: From Voluntary Restraint to a Voluntary Price Premium. *Environmental and Resource Economics* 40, 195–215.

Maddala, G.S., R.P. Trost, H. Li, and F. Joutz. 1997. Estimation of short-run and long-run elasticities of energy demand from panel data using shrinkage estimators. Journal of Business & Economic Statistics. 15 (1): 90–100.

Rivers, N., and B. Schaufele. 2013. Carbon Tax Salience and Gasoline Demand. Working Paper, Ottawa, ON: Graduate School of Public and International Affairs and Institute of the Environment, University of Ottawa.

## CHAPTER 2

## Fat Tax: More Trouble Than it's Worth?

ABSTRACT

The incidence of obesity is increasing in Canada (Statistics Canada, 2011a). I assess the effects of four hypothetical food policies on food and beverage purchases by Canadian households across different income groups. I use Statistics Canada's 2001 Food Expenditure Survey (FES) to estimate consumer responses to price changes of thirteen foods and beverages. I estimate the parameters from a censored Exact Affine Stone Index (EASI) demand system. A two-step estimation procedure is used to deal with censored observations. The simulation results suggest that when fat tax revenues are recycled as lump-sum transfers to households, this policy would be the most efficient and progressive scenario from both economic and health perspectives.

*Keywords:* Obesity, EASI demand, tax reforms, censored demand, nutrient elasticities

## 2.1. Introduction

The incidence of obesity is increasing in both developed and some developing countries. Based on recent research from Statistics Canada about one-quarter of Canadian adults are obese (Statistics Canada, 2011b) and in 2008 62% are either obese or overweight (Public Health Agency of Canada, 2011). Health Canada (2006) advocates that “eating a nutritious and balanced diet is one of the best ways to protect and promote good health.” Public health researchers are now considering possible causes and policy solutions for obesity. One of the potential policies is application of a fat tax (tax on foods high in calories, fat and sugar). Like taxes on alcohol and tobacco, a fat tax is designed not to raise revenue but to alter consumers' behaviour, and the more consumers succeed in changing behaviour the less revenue food taxes generate. Because tobacco taxation has been cited as one of the most effective public health tools for tobacco control, many believe that the tobacco model could be successfully replicated on taxing food (Chaloupkal,Yurekli, and Fong, 2012). However, the use of fat taxes has met resistance. Denmark—the first country to implement a fat tax—terminated its fat tax after one year and cancelled plans for an additional tax on sugars, due to concerns that the fat tax punished the poor, threatened Danish jobs, and increased cross-border shopping (The New York Times, 2012; Stafford, 2012).

Whether food taxes will reduce obesity rates remains open to debate. The use of tax policy to influence food prices “in ways that encourage healthy eating” has been supported by the World Health Organization (WHO) and is under active consideration by medical associations and public health researchers. These groups advocate utilizing a fat tax on specific food groups (*i.e.* sugar sweetened beverages or fast foods) to modify the nutrient intake and reduce average body weights (O'Donoghue *et al*. 2006; Cash *et al.* 2007; Brownell *et al.*2009; Kamerow, 2010). Some economists have challenged the ability of food taxes to significantly decrease calorie intake (Becker, 2009; Posner, 2009). They argue that such a tax ignores the possibility that consumers will substitute for other untaxed unhealthy food. For example, a soda tax may reduce consumption of sugar sweetened beverages, but increase consumption of snacks high in sugar and fat. Alternatively, a fat tax may have a positive effect on fiber consumption accompanied by an increase in unhealthy nutrients or calories (Okrent and Alston, 2012). Considering the interdependence of food consumption choices, there is no clear evidence showing that a fat tax contributes to decreased energy intake (Allais *et al*. 2011; Nordstrom *et al*. 2009 and 2011(b); Finkelstein *et al*. 2013).

Perhaps most importantly, previous economic research suggests that food taxes are regressive—poor consumers suffer much greater welfare losses from the taxes than do wealthier consumers (Chouinard *et al*. 2007; Zhen *et al.* 2011). Several studies examine revenue-neutral tax reforms on food products. Smed et al. (2007) analyze the impact of revenue-neutral scenarios based on a broad number of food groups, such as taxes on fatty meats, subsidies on fresh fruits and vegetables, a tax on specific nutrients (saturated fat/sugar), and a subsidy on fiber. They find that young consumers are most responsive to taxes on saturated fat; response to a subsidy on fibre does not vary across demographic groups; and the demand for sugar increases as an undesired side effect in those two scenarios. Nordstrom et al. (2011(a) and 2011(b)) discuss revenue-neutral tax reforms dealing with grain product consumption. Their revenue-neutral scenarios include subsidies of high-fibre breakfast cereals and bread funded by taxes on bakery goods and ready-made meals. They find that tax reforms aimed at increasing high-fibre grain consumption are progressive. They also find that low income households benefit financially from all tax reforms. Cash et al. (2006) investigate the possible health effects of a ‘‘thin subsidy’’ on fruits and vegetables and find a significant decline in some diseases once subsidies are imposed.

There is little previous empirical work exploring more comprehensive tax reforms and their related impacts on household income and health.[1] Revenue recycling is one method of reducing the regressivity of fat taxes. The revenue collected by a fat tax could be used to subsidise healthy foods, subsidise gym memberships, or support monetary transfers to households.[2] In this chapter, I compare four policies, including a stand-alone fat tax on sugar sweetened beverages (SSBs), sugar-fat products, and salt-fat products, a stand-alone food subsidy on fruits and vegetables, a revenue- neutral fat tax with a lump-sum transfer to households, and a revenue- neutral fat tax combined with the tax revenue used to subsidise fruits and vegetables.

The aggregate tax burden, income regressivity, and nutritional impacts of these four food policies are investigated. First, price elasticities varied by income terciles are estimated using a two-step approximate censored Exact Affine Stone Index (EASI) demand model. Second, a series of simulations of the impacts of hypothetical taxes and subsidies on household welfare are reported and evaluated. Third, an evaluation of changes in nutrient consumption due to the four policies is presented. Finally, simulations of series of tax reforms are conducted. Both the health

---

[1] The distributional effects of environmental tax reforms are widely discussed in the literature (West et al. 2004; Bento et al. 2005 and 2009).

[2] So far no government has directly subsidised healthy food, although some countries have a policy of zero rating VAT for certain foods (Smed, 2012). Australia has long allowed consumers to take tax deductions for membership fees in weight-loss programs (Cash, 2006).

impact and economic impact are estimated. I find that recycling revenue through a lump-sum transfer to households is the most effective policy from both economic and health perspectives. Compared with the other scenarios—a fat tax without redistribution, a subsidy on fruit and vegetables, and a revenue- neutral approach using the collected fat tax revenue to subsidise fruits and vegetables—using the fat tax revenue to fund a lump-sum transfer both benefits the poor and decreases household caloric intake.

The rest of the chapter is organized as follows. Section 2.2 presents a literature review on demand systems and the censored-data problem that is encountered when using micro data. Section 2.3 specifies the model and the estimation procedure. Section 2.4 outlines the empirical estimation results, including data description, estimation procedure, model tests and elasticity estimation. Section 2.5 presents simulation results under four food policies. Section 2.6 concludes the study.

## 2.2. Literature Review

In this section, I first discuss the advantages and disadvantages of using various types of demand system models. Then, I focus on censoring issues due to the use of household-level food consumption data. Finally, I present the empirical model used in the analysis.

### 2.2.1. *Demand System Models*

The *Almost Ideal Demand System* (AIDS) model of Deaton and Muellbauer (1980) has been widely used in demand analysis. Owing to its simplicity, the linear approximate almost ideal demand system (LA/AIDS) is popular in empirical studies. Both AIDS and LA/AIDS, with budget shares of the various commodities linearly related to the logarithm of real total expenditure, assume linear Engel curves. The Quadratic Almost Ideal Demand System (QUAIDS) is a further development of the AIDS model, which allows a quadratic Engel curve (Blundell *et al.* 1993; Banks *et al.*1997).[3]

Lewbel and Pendakur (2009) (henceforth "LP") generated a new demand estimation approach—the Exact Affine Stone Index (EASI) model. Like AIDS, it is linear in parameters. The theoretical model is generated from Hicksian demand and permits any shape (including non-linear) of Engel curves (i.e. S-shaped Engel curve), which allows goods to be luxuries at some income levels and necessities at others (Pendakur 1999; Blundell et al. 2007). Budget share equations that are non-linear in income/expenditure can provide an accurate estimation of the Engel relationship and related welfare effects in micro-level data. McAleer et al. (2008) estimate flexible functional forms of the EASI model and compare the estimated results with an AIDS model.  They find that the EASI demand model is able to detect nuanced differences in Engel curves.

2.2.2. *Censoring*

One problem when using micro data is the existence of zero observations on the dependent or explanatory variables. This censoring feature, most notable in demand estimation using disaggregate data, needs to be addressed in order to obtain consistent parameters and elasticities. In the case of food expenditure, there are three possible sources of censoring:

(i) Corner solution: the household does not purchase the item due to economic

[3] A quadratic Engel curve implies that as income increases, the budget share is not necessarily constant. Instead, it allows budget share to vary with income.

reasons, e.g. price or income;

(ii) Abstention: the household does not participate in the market due to non-economic reasons, e.g. no meat expenditure due to vegetarian preferences;

(iii) Infrequency of purchase: survey period is shorter than the good's purchasing cycle thus failing to include a positive purchase by a household that consumes the good.

To address the censoring issue, Heien and Wessells (1990) applied the Heckman (1976) two step sample selection estimation to the demand system. Heien and Wessells' (1990) method proceeds as follows: (i) use Maximum Likelihood (ML) probit to estimate the likelihood that the good is purchased and (ii) estimate the demand system with each equation augmented by an inverse Mills ratio derived from the first step.[4] Though inconsistent, this method is widely used in agricultural and environmental economics in order to deal with censoring issues (Alderman and Sahn 1993; West and Williams 2004; Nordstrom and Thunstrom 2009).

Shonkwiler and Yen (1999) demonstrated the poor performance of the Heien and Wessells' (1990) estimator by conducting Monte Carlo simulations, and suggested an alternative consistent two-step estimation procedure. By assuming that the disturbances in the first step and the second step follow a bivariate normal distribution, Shonkwiler and Yen's (1999) method is shown to be unbiased and consistent.

## 2.3. Empirical Model and Methodology

In this research, I apply a two-step linear approximate EASI demand system to data from the Statistics Canada 2001 Food Expenditure Survey (FES). The

[4] Inverse mills ratio is defined as the ratio of the probability density function to the cumulative distribution function of a distribution. It is used as an instrumental variable in the second step estimation.

application of EASI demand is used to avoid linear Engel curves. Shonkwiler and Yen's (1999) two step estimation is used to address the censoring issue. The linear approximate uncensored EASI demand system without interactions between prices and log real expenditures can be summarized by the following pair of equations:

$$w_{ih} = \sum_{k=1}^{N} \alpha_{ik} ln(p_{kh}) + \sum_{r=0}^{R} \beta_{ir} y_h^r + \sum_{t=1}^{T} \gamma_{it} z_{th} + e_{ih} \quad (1)$$

$$y_h = lnx_h - \sum_{i=1}^{N} \overline{w}_i \ln(p_{ih}) \quad (2)$$

for $i = 1, \ldots, N$ food categories and $h = 1, \ldots, H$ households. In equation (1), $w_{ih}$ is the budget share for food product $i$ in household $h$; $p_{kh}$ is the price of food $k$ for household $h$, $k = 1,2 \ldots, N$ food categories; the parameter $\alpha_{ik}$ captures price effects; $y_h$ is the log of real expenditure[5] of household $h$; $r = 0, \ldots, R$ is the exponent and it can be any higher order polynomial satisfying the restriction $R < N$; the parameter $\beta_{ir}$ captures the shape of the Engel curve; $\boldsymbol{z_h} = (z_{th}, t = 1, \ldots, T)$ is a vector of household characteristics with $t$ indexing demographic variables; and the parameter $\gamma_{it}$ captures demographic shifters in budget shares. Finally, the error term $e_{ih}$ incorporates unobserved preference heterogeneity into budget shares.[6] In equation (2), $x_h$ is the total food expenditure and $\overline{w}_i$ is the sample average budget share of food item $i$ over all households.[7] Theoretical constraints are imposed - the system of demand functions is homogeneous of degree zero in prices and total expenditure, Slutsky symmetry of the demand equations holds ($\alpha_{ik} = \alpha_{ki}$), and that budget shares sum to one ($\sum_{i=1}^{N} \boldsymbol{w_i} = 1$).[8]

---

[5] LP demonstrate that under some regularity conditions, log real expenditure is equivalent to utility. That is, $y = u$, where u is defined as utility.

[6] For example, in the food demand system, unobserved heterogeneity refers to factors that determine the budget share but are not observed in the data. (*i.e.*, consumer taste).

[7] $\sum_{i=1}^{N} \overline{w}_i \ln(p_{ih})$ is also called Stone price index (Deaton *et al.*, 1980).

[8] The following conditions ensure the system is homogeneous of degree zero in prices and total expenditure: $\sum_{i=1}^{N} \beta_{i0} = 1$, $\sum_{i=1}^{N} \beta_{ir} = 0$ for $r = 1, \ldots R$; $\sum_{i=1}^{N} \gamma_{it} = 0$; $\sum_{i=1}^{N} \alpha_{ik} = 0$; $\sum_{k=1}^{N} \alpha_{ik} = 0$.

In this section, a censored demand system developed by Shonkwiler and Yen (1999) is considered. Denote a latent budget share of commodity $i$ and household $h$ as $w_{ih}(X_h;\theta)$, where $X_h$ is a vector containing all the explanatory variables ($p_{kh}, y_h,$ and $z_{th}$) used in the demand system for household $h$ and $\theta$ is the vector of related parameters ($\alpha_{ik}$, $\beta_{ir}$, and $\gamma_{it}$). The censoring rule that relates the latent budget share of the $i^{th}$ food category and $h^{th}$ household to the observed budget share $s_{ih}$ is as follows:

$$s_{ih} = \begin{cases} w_{ih}(X_h;\theta) + e_{ih} & \text{if } \boldsymbol{m}_{\boldsymbol{ih}}'\tau_i + v_{ih} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

where $s_{ih}$ is the observed budget share, $\boldsymbol{m}_{\boldsymbol{ih}}$ is a vector of exogenous variables used to describe household purchasing decisions, $\tau_i$ is the related vector of parameters, and $e_{ih}$ and $v_{ih}$ are random error terms. I assume the error terms $(e_{ih}, v_{ih})'$ follow a joint bivariate normal distribution.

The purchase decision is modeled with a binary probit model:

$$d_{ih} = \mathrm{I}\left(\boldsymbol{m}_{\boldsymbol{ih}}'\tau_i + v_{ih} > 0\right) \tag{4}$$

where the variable $d_{ih}$ denotes an indicator function of whether the household $h$ decides to purchase food item $i$ with $d_{ih}$=1 for purchase and $d_{ih} = 0$ for no purchase. Using equation (3), the mean of $s_{ih}$ conditional on a positive purchase is:

$$E\left(s_{ih} \middle| v_{ih} > -\boldsymbol{m}_{\boldsymbol{ih}}'\tau_i\right) = w_{ih}(X_h;\theta) + \psi_i \phi\left(\boldsymbol{m}_{\boldsymbol{ih}}'\tau_i\right)/\Phi\left(\boldsymbol{m}_{\boldsymbol{ih}}'\tau_i\right) \tag{5}$$

where $\phi(.)$ and $\Phi(.)$ are the normal probability density and cumulative distribution functions, respectively. $\phi\left(\boldsymbol{m}_{\boldsymbol{ih}}'\tau_i\right)/\Phi\left(\boldsymbol{m}_{\boldsymbol{ih}}'\tau_i\right)$ is the inverse mills ratio of the $i$th food item for the $h$th household, and $\psi_i$ is the related coefficient used to capture the prevalence of censoring issue.[9] The unconditional mean is defined as the conditional mean value multiplied by the probability of a positive observation.

$$\mathrm{E}(s_{ih}) = E(s_{ih}|v_{ih} > -\boldsymbol{m}'_{ih}\tau_i)\Pr(v_{ih} > -\boldsymbol{m}'_{ih}\tau_i) + E(s_{ih}|v_{ih} < -\boldsymbol{m}'_{ih}\tau_i)\Pr(v_{ih} < -\boldsymbol{m}'_{ih}\tau_i) \quad (6)$$

Since $\Pr(v_{ih} > -\boldsymbol{m}'_{ih}\tau_i) = \Phi(\boldsymbol{m}'_{ih}\tau_i)$ and $E(s_{ih}|v_{ih} < -\boldsymbol{m}'_{ih}\tau_i) = 0$, the unconditional mean of $s_{ih}$ is:

$$\mathrm{E}(s_{ih}) = \Phi(\boldsymbol{m}'_{ih}\tau_i)w_{ih}(X_h;\theta) + \psi_i\phi(\boldsymbol{m}'_{ih}\tau_i) \quad (7)$$

Based on equation (3), the observed budget share equation is written as:

$$s_{ih} = \Phi(\boldsymbol{m}'_{ih}\tau_i)w_{ih}(X_h;\theta) + \psi_i\phi(\boldsymbol{m}'_{ih}\tau_i) + \xi_{ih} \quad (8)$$

where $\xi_{ih} = s_{ih} - E(s_{ih})$.

When the *approximate* EASI demand system is applied to equation (8), the budget share is written as:

$$s_{ih} = \Phi(\boldsymbol{m}'_{ih}\tau_i)(\textstyle\sum_{k=1}^{N}\alpha_{ik}ln(p_{kh}) + \sum_{r=0}^{R}\beta_{ir}y_h^r + \sum_{t=1}^{T}\gamma_{it}\, z_{th}) + \psi_i\phi(\boldsymbol{m}'_{ih}\tau_i) + \xi_{ih} \quad (9)$$

The estimation procedure for this two-step *approximate* censored EASI demand model is as follows:

1. In the first step, a probit model is used for equation (4). I obtain the estimated coefficients $\widehat{\tau_i}$ for $\tau_i$ and the estimated cumulative distribution function

[9] Heckman(1976) used the inverse mills ratio as an instrument which is incorporated in the second stage of the censored equation estimation.

$\widehat{\Phi}(\boldsymbol{m}_{ih}'\widehat{\tau_\iota})$ and probability density function $\widehat{\phi}(\boldsymbol{m}_{ih}'\widehat{\tau_\iota})$

2. In the second step, I substitute $\widehat{\Phi}(\boldsymbol{m}_{ih}'\widehat{\tau_\iota})$ and $\widehat{\phi}(\boldsymbol{m}_{ih}'\widehat{\tau_\iota})$ into the system of primary equations in (9) and estimate the parameters of the censored *approximate* EASI demand system.

The budget share equation is:

$$s_{ih} = \widehat{\Phi}(\boldsymbol{m}_{ih}'\widehat{\tau_\iota})\left(\sum_{k=1}^{N}\alpha_{ik}ln(p_{kh}) + \sum_{r=0}^{R}\beta_{ir}y_h^r + \sum_{t=1}^{T}\gamma_{it}\, z_{th}\right)$$

$$+\psi_i\hat{\phi}(\boldsymbol{m}_{ih}'\widehat{\tau_\iota}) + \eta_{ih} \tag{10}$$

where the error term is $\eta_{ih} = \xi_{ih} + [\Phi(\boldsymbol{m}_{ih}'\tau_i) - \widehat{\Phi}(\boldsymbol{m}_{ih}'\widehat{\tau_\iota})]w_{ih}(X_h;\theta) + \psi_i[\phi(\boldsymbol{m}_{ih}'\tau_i) - \hat{\phi}(\boldsymbol{m}_{ih}'\widehat{\tau_\iota})]$. Since the sequential two-step estimator of $\hat{\theta}$ depends in part on a consistent first-stage estimator of $\widehat{\tau_\iota}$, the asymptotic distribution of $\hat{\theta}$ depends on $\widehat{\tau_\iota}$. As shown by Murphy and Topel (1985), the resulting standard errors are incorrect since this two-step procedure fails to account for the fact that imputed regressors are measured with sampling errors, so the hypothesis tests based on the estimated covariance matrix of the second step estimator are biased, even in large samples. Currently, a simple approach to address this bias is to bootstrap the parameter estimates in both step one and step two in order to generate efficient standard errors (Cameron, 2010; Sam *et al.*, 2010). The standard errors of the two step estimator are computed by nonparametric bootstrap replicates. In this research, the whole *N* equation system is estimated with the Seemingly Unrelated Regression (SUR) procedure.[10]

## 2.4. Empirical Estimation

### 2.4.1. *Data Description*

In this research, I use the 2001 Canadian Food Expenditure Survey (FES), which is a two-week survey conducted by Statistics Canada. Starting from 1984, Statistics Canada has conducted six rounds of the survey and FES 2001 is the latest one. In FES 2001, respondents kept detailed diaries of all food expenditures including both food at home and food away from home. The detailed food category file presents expenditures and quantities of 257 food categories by household. The FES 2001 includes 5,643 households from the total of 5,999 households that were interviewed over the course of a twelve-month period, and households in ten provinces were surveyed.[11] When compared with the previous version of the survey, FES 2001 provides less demographic information, but is considered to be a better quality survey since in FES 2001 respondents were asked to attach their grocery store receipts to the diaries.[12] Statistics Canada has derived a set of household weights for use with the publicly available microdata files that take into account survey design and nonresponse.[13] When weighted, the sample is generally representative of the Canadian population. In all subsequent analyses the results incorporate these weights.

---

[10] As pointed out by Yen et al (2002), using this two-step estimation, the deterministic part does not add up to unity. As a consequence, the second step error terms do not add up to zero across equations and the non-inevitability of the covariance matrix does not arise when estimating the system of all *N* equations. As a result, there is no need to delete one equation from the system.
[11] It excludes the records of Whitehorse, Yellowknife and Iqaluit.
[12] FES 2001 does not contain education, types of work, working hours, or social assistance, which are included in the previous rounds.
[13] To estimate population characteristics from a sample survey, each sampled household in FES is assigned a survey weight representing a certain number of other households in addition to itself. Each household is given a weight equal to the inverse of its selection probability.

Among the surveyed households, 237 completed only the first week questionnaire and 18 households completed only the second week questionnaire. The remainder of the households reported both. I convert all expenditures and quantities to a weekly basis.

For the purpose of this research, 246 food items purchased from stores are aggregated into 13 categories, taking into account similarities in the nutritional content of the products, consumer preferences, and consumer willingness to substitute one product for another. The following categories of food are defined: meats (beef, pork, poultry, and other meat including cold cuts); fish and seafood; dairy (cream, milk, cheese and yogurt, and other dairy products); eggs; bakery products; cereal and pasta grain products; fruits; vegetables; fat and oil (butter, margarine and oil); sugar sweetened beverages (carbonated beverage, fruit drinks); salt-fat snacks (potato chips and popcorn); sugar-fat products (candy, chocolate, pastry and ice cream); and prepared meals (frozen dinner/food, soup, sandwiches, and hot food preparations). These food categories are based on groups in the Health Canada Commodity Nutrient File (2010). Allais *et al.* (2010) set up 22 food groups. I combine some food items and focus on some food groups that have higher energy and calories, such as SSBs, salt-fat products, sugar-fat products, and prepared meals.

Prior to aggregation, the quantities of each category of goods were converted to kilograms so that the same unit of measurement is used for each commodity. The conversion factors used are those developed by Agriculture and Agri-Food Canada (Pomboza et al., 2007).

For each food item, the quantity consumed and amounts spent during the survey period are recorded. The price for each item was not provided directly. For many observations, the price of each category of food is derived as a unit value for each household. However, prices are not observed if the households have zero expenditure on a particular food category. A simple method to handle this is to use a regional sample average (Kasteridis et al., 2011). In this research, I expect that prices vary across both geographic region and size of area of residence. I replace missing prices with the region averages among the consuming households, where the regions are defined by five geographic regions (Atlantic, Quebec, Ontario, Prairies, British Columbia) and the size of the area of residence is divided into rural areas, areas with a population less than 30,000, and areas with a population over 30,000.[14]

The final sample is comprised of 4974 observations. The frequency of observations with zero consumption are as follows: meat (9.23%), fish and seafood (56.09%), dairy (5.56%), eggs (45.51%), bakery (4.80%), cereal and pasta (28.87%), fruit (7.71%), vegetable (7.43%), fat and oil (42.90%), SSBs (23.55%), salt-fat products (50.33%), sugar fat products (37.91%), and prepared meals (56.10%).[15] Censoring therefore appears to be a problem in fish and seafood, eggs, cereal and pasta, fat and oil, SSBs, salt-fat products, sugar fat products and prepared meals.

In the FES 2001, the surveyed households were asked to report their income from all sources and twelve income groups were defined. The upper and lower bounds for each income group are reported. In this chapter, I take the average of the lower and higher bound and interpret it as a proxy for the household income before tax. For the purpose of comparison, I divide the sample into three terciles based on income.

[14] Rural area is a geographic area that is located outside the cities and towns.

[15] Household with zero purchase on FAH or household with missing information on the demographic variables are dropped in this research.

These terciles are intended to reflect individuals' standard of living, and clearly a given level of household income represents a higher living standard if that household only includes one person than if it includes several people. I use the Organization for Economic Co-operation and Development (OECD) equivalence scale to adjust the total household income for different family sizes. The scale assigns the oldest person in the family a factor of 1, family members aged 15 and over are assigned a factor of 0.5, and all other family members under age 15 are assigned a factor of 0.3.

### 2.4.2 *Estimation Procedure*

The first step probit equation includes several demographic variables, such as prices of food, age of the household head, gender of the household head, household size, dummy variables indicating urbanization (rural, population less than 30,000, and population greater than 30,000), regional dummies (Atlantic, Ontario, Quebec, Prairie, British Columbia), quarterly dummies, and household dummies for couples without children, couples with children, one person households, lone parent households with children, and other households.[16] I also include the frequency of food purchases in the first step probit.[17] Households with more shopping trips within a week are less likely to purchase in bulk and therefore are more likely to purchase items within the survey period. Total number of meals away from home and total expenditure on food away from home are also included as explanatory variables in the first step probit model. It is reasonable to think that households that spend more on food away from home are less likely to purchase food items for consumption at home during the survey period.

Food prices, log of stone-deflated expenditure, demographic variables, and the normal probability density and cumulative distribution functions estimated from

[16] The first-step probit equation is equation (4) from the section above.
[17] Measured by counting the number of shopping trips within 14 days.

the first step probit are used as explanatory variables in the second step of the censored demand system model. The demographic variables in the second step include the age of the household head, gender of the household head, number of household members, regional dummies, urbanization dummies, dummies for household types, and the inverse mills ratio. Frequency of food purchases, total number of meals away from home, and total expenditure on food away from home are excluded from the second step and therefore serve as exclusion restrictions.

Table 2.1 contains descriptive statistics of these variables. The summary statistics are reported for both the aggregated dataset and by income quintile. Note that among all the thirteen food categories, the unit values tend to be higher in the high-income terciles. This likely reflects higher-income households' purchases of higher-quality food and willingness to pay premiums for convenience. Within dairy, high-income households spend larger shares of their food budget on cheese and smaller shares on fluid milk. With respect to the food budget share, high-income households spend larger shares of their food budget on fish, fruits, vegetables, and prepared meals, whereas low-income households spend more on dairy products, and fats and oil. Regarding to the household size, the medium-income households tend to have a larger household size than the other terciles. Further, low income households tend to have more children, as do medium income households. High income households tend to have the fewest children among the terciles. I estimate equation (10) using SUR.

Table 2.1. *Summary Statistics*

| | Aggregate (N=4974) | | Low Income (N=1664) | | Medium Income (N=1669) | | High Income (N=1641) | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Standard deviation | Mean | Standard deviation | Mean | Standard deviation | Mean | Standard deviation |
| *Natural log of prices:* | | | | | | | | |
| Meat | 1.99 | 0.40 | 1.89 | 0.43 | 1.98 | 0.37 | 2.11 | 0.39 |
| Fish | 2.44 | 0.35 | 2.39 | 0.33 | 2.43 | 0.35 | 2.50 | 0.37 |
| Dairy | 0.85 | 0.61 | 0.77 | 0.62 | 0.84 | 0.59 | 0.95 | 0.64 |
| Eggs | 1.22 | 0.18 | 1.22 | 0.17 | 1.22 | 0.18 | 1.24 | 0.20 |
| Bakery | 1.45 | 0.43 | 1.34 | 0.45 | 1.46 | 0.42 | 1.57 | 0.41 |
| Cereal | 1.48 | 0.56 | 1.46 | 0.55 | 1.47 | 0.57 | 1.54 | 0.55 |
| Fruits | 0.76 | 0.40 | 0.73 | 0.41 | 0.74 | 0.39 | 0.83 | 0.42 |
| Vegetables | 0.83 | 0.51 | 0.76 | 0.54 | 0.81 | 0.51 | 0.96 | 0.48 |
| Fat&Oil | 1.54 | 0.41 | 1.48 | 0.41 | 1.53 | 0.41 | 1.64 | 0.37 |
| Beverage | 0.77 | 1.02 | 0.84 | 1.01 | 0.74 | 1.03 | 0.80 | 1.01 |
| Salt-fat products | 2.18 | 0.28 | 2.18 | 0.26 | 2.17 | 0.29 | 2.21 | 0.28 |
| Sugar-fat products | 2.14 | 0.58 | 2.11 | 0.59 | 2.14 | 0.58 | 2.19 | 0.55 |
| Prepared Meals | 1.80 | 0.49 | 1.75 | 0.49 | 1.79 | 0.50 | 1.90 | 0.48 |
| *Budget share:* | | | | | | | | |
| Meat | 0.21 | 0.14 | 0.20 | 0.15 | 0.21 | 0.13 | 0.21 | 0.13 |
| Fish | 0.03 | 0.06 | 0.02 | 0.05 | 0.03 | 0.06 | 0.04 | 0.06 |
| Dairy | 0.14 | 0.11 | 0.14 | 0.13 | 0.13 | 0.10 | 0.13 | 0.09 |
| Eggs | 0.01 | 0.02 | 0.02 | 0.03 | 0.01 | 0.02 | 0.01 | 0.02 |
| Bakery | 0.11 | 0.08 | 0.11 | 0.10 | 0.11 | 0.08 | 0.10 | 0.07 |
| Cereal | 0.04 | 0.05 | 0.05 | 0.06 | 0.05 | 0.05 | 0.04 | 0.05 |
| Fruits | 0.12 | 0.09 | 0.12 | 0.11 | 0.12 | 0.09 | 0.13 | 0.09 |
| Vegetables | 0.11 | 0.08 | 0.11 | 0.09 | 0.11 | 0.08 | 0.12 | 0.08 |
| Fat&Oil | 0.02 | 0.04 | 0.03 | 0.04 | 0.03 | 0.04 | 0.02 | 0.03 |
| Beverage | 0.07 | 0.08 | 0.07 | 0.10 | 0.07 | 0.08 | 0.06 | 0.07 |
| Salt-fat products | 0.02 | 0.04 | 0.02 | 0.04 | 0.02 | 0.04 | 0.02 | 0.04 |
| Sugar-fat products | 0.04 | 0.06 | 0.04 | 0.07 | 0.04 | 0.06 | 0.04 | 0.05 |
| Prepared Meals | 0.07 | 0.08 | 0.06 | 0.09 | 0.07 | 0.08 | 0.08 | 0.08 |
| *Age(years)* | 48.06 | 15.46 | 48.70 | 17.68 | 48.45 | 15.66 | 46.36 | 11.98 |
| *Household size* | 2.60 | 1.33 | 2.49 | 1.48 | 2.66 | 1.27 | 2.56 | 1.30 |
| *Quarter (season):* | | | | | | | | |
| First Quarter | 0.26 | 0.44 | 0.30 | 0.46 | 0.25 | 0.44 | 0.24 | 0.43 |
| Second Quarter | 0.23 | 0.42 | 0.25 | 0.43 | 0.24 | 0.42 | 0.21 | 0.41 |
| Third Quarter | 0.24 | 0.43 | 0.22 | 0.41 | 0.24 | 0.43 | 0.26 | 0.44 |
| Fourth Quarter | 0.26 | 0.44 | 0.23 | 0.42 | 0.27 | 0.44 | 0.28 | 0.45 |
| *Household Type:* | | | | | | | | |
| Couple with no children | 0.22 | 0.42 | 0.33 | 0.47 | 0.18 | 0.38 | 0.23 | 0.42 |
| Couple with children | 0.27 | 0.44 | 0.14 | 0.35 | 0.30 | 0.46 | 0.30 | 0.46 |
| One person household | 0.37 | 0.48 | 0.28 | 0.45 | 0.40 | 0.49 | 0.40 | 0.49 |
| Lone parent household with children | 0.07 | 0.26 | 0.15 | 0.36 | 0.06 | 0.24 | 0.02 | 0.15 |
| Other household | 0.06 | 0.24 | 0.08 | 0.28 | 0.06 | 0.24 | 0.04 | 0.20 |
| *Area:* | | | | | | | | |
| Population >=30,000 | 0.72 | 0.45 | 0.63 | 0.48 | 0.69 | 0.46 | 0.86 | 0.34 |
| Population<=30,000 | 0.12 | 0.33 | 0.15 | 0.36 | 0.13 | 0.33 | 0.07 | 0.25 |
| Rural | 0.16 | 0.37 | 0.22 | 0.41 | 0.18 | 0.38 | 0.07 | 0.26 |
| *Region:* | | | | | | | | |
| Atlantic | 0.13 | 0.33 | 0.18 | 0.38 | 0.13 | 0.34 | 0.06 | 0.25 |
| Ontario | 0.23 | 0.42 | 0.26 | 0.44 | 0.23 | 0.42 | 0.20 | 0.40 |
| Quebec | 0.28 | 0.45 | 0.20 | 0.40 | 0.27 | 0.45 | 0.36 | 0.48 |
| Prairies | 0.21 | 0.41 | 0.21 | 0.41 | 0.21 | 0.41 | 0.21 | 0.41 |
| British Columbia | 0.16 | 0.36 | 0.15 | 0.36 | 0.16 | 0.36 | 0.16 | 0.37 |

| | Aggregate (N=4974) | | Low Income (N=1664) | | Medium Income (N=1669) | | High Income (N=1641) | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Standard deviation | Mean | Standard deviation | Mean | Standard deviation | Mean | Standard deviation |
| *Household with children* | 0.32 | 0.47 | 0.35 | 0.48 | 0.33 | 0.47 | 0.25 | 0.44 |
| *Frequency of purchase* | 2.53 | 1.33 | 2.39 | 1.36 | 2.59 | 1.35 | 2.49 | 1.26 |
| *Meals away from home* | 4.18 | 5.11 | 2.45 | 3.82 | 4.10 | 4.91 | 6.18 | 6.04 |
| *Total expenditure on FAFH* | 38.80 | 52.62 | 18.87 | 29.70 | 36.29 | 45.96 | 66.26 | 73.05 |
| *Gender of reference person(male=1)* | 0.42 | 0.49 | 0.35 | 0.48 | 0.41 | 0.49 | 0.51 | 0.50 |

### 2.4.3 *Model Tests*

As stated by LP, in the EASI demand system the proper degree of real expenditure/income polynomials should be determined through tests. In this section, I test the model specifications. First, I use a Wald test to determine if the approximate EASI model provides a more accurate description of the data than the approximate QUAIDS. Second, the Akaike Information Criterion (AIC) is used to determine the adequacy of the fifth-order polynomial in $y$.[18]

Table 2.2 gives Wald tests for various hypotheses in terms of model specification using the FES 2001. A 1% critical value is used in all hypothesis testing. Since our two-step censored approximate EASI demand nests the two-step censored approximate QUAIDS and two step censored LA/AIDS, I first test if the non-quadratic sections can be statistically rejected in the two-step censored approximate EASI demands using a Wald-test.[19] The upper panel of Table 2.2 reports that one cannot model the polynomial in $y$ as quadratic: the tests suggest meat, dairy, bakery, cereal, fruit, fat and oil, and salt-fat products need higher order polynomial Engel curves.[20] These departures from the quadratic Engel curves suggest that higher order polynomial Engel curves should be considered in the food demand analysis.

[18] LP find that the fifth-order polynomial in $y$ is adequate for their data.
[19] Wald -test is widely used for nested model test.
[20] I use a Wald-test for each food category. Assume I test if $y^3, y^4, y^5$ can be statistically rejected for each food category. $\beta_{ir}$ is the coefficient of log real expenditure, where i=1,....13; r=1,...5

Table 2.2. *Model Tests (Wald test)*

| | Test | df | Test stats ($\chi^2$) | P-value | Reject/Not |
|---|---|---|---|---|---|
| Meat | H0: Quadratic<br>H1: Non-Quadratic | 3 | 23.57 | 0.0000 | Reject |
| Salt-fat | H0: Quadratic<br>H1: Non-Quadratic | 3 | 41.23 | 0.0000 | Reject |
| Sugar-fat | H0: Quadratic<br>H1: Non-Quadratic | 3 | 9.46 | 0.0238 | Fail to reject |
| Prepared meals | H0: Quadratic<br>H1: Non-Quadratic | 3 | 9.75 | 0.0209 | Fail to reject |
| Fish | H0: Quadratic<br>H1: Non-Quadratic | 3 | 8.39 | 0.0386 | Fail to reject |
| Dairy | H0: Quadratic<br>H1: Non-Quadratic | 3 | 51.33 | 0.0000 | Reject |
| Eggs | H0: Quadratic<br>H1: Non-Quadratic | 3 | 8.58 | 0.0354 | Fail to reject |
| Bakery | H0: Quadratic<br>H1: Non-Quadratic | 3 | 47.91 | 0.0000 | Reject |
| Cereal | H0: Quadratic<br>H1: Non-Quadratic | 3 | 15.05 | 0.0018 | Reject |
| Fruit | H0: Quadratic<br>H1: Non-Quadratic | 3 | 19.56 | 0.0002 | Reject |
| Vegetable | H0: Quadratic<br>H1: Non-Quadratic | 3 | 0.95 | 0.8131 | Fail to reject |
| Fat and Oil | H0: Quadratic<br>H1: Non-Quadratic | 3 | 37.31 | 0.0000 | Reject |
| SSBs | H0: Quadratic<br>H1: Non-Quadratic | 3 | 7.42 | 0.0596 | Fail to reject |
| Exclusion | H0: Exclusion of $y^5$<br>H1: Non- exclusion of $y^5$ | 13 | 90.85 | 0.0000 | Reject |
| Exclusion | H0: Exclusion of $y^6$<br>H1: Non- exclusion of $y^6$ | 13 | 39.78 | 0.0001 | Reject |
| Exclusion | H0: Exclusion of $y^7$<br>H1: Non- exclusion of $y^7$ | 13 | 10.21 | 0.6770 | Fail to reject |

Regarding the expenditure effects, I check for adequacy of our fifth-order polynomial in $y$ by adding $y^6$ and $y^7$ term to the model.[21] The lower panel of Table 2.2 reports the Wald-test results when higher order polynomials (i.e. $y^6$ and $y^7$) are included in the model. When $y^7$ is included, the Wald-test rejects it at 1% critical value. However, the Wald-test fails to reject $y^6$ in the demand system.[22] Therefore,

---

H0: $\beta_{i3}$=$\beta_{i4}$=$\beta_{i5}$=0
H1: does not equal to zero

[21] LP suggest a fifth-order polynomial in *y* in their research.

[22] This is the test for the whole demand system. Assume I test the adequacy of $y^6$. $\beta_{ir}$ is the coefficient on log real expenditure, where i=1,....13; r=6

$H_0$: $\beta_{16}$=$\beta_{26}$=....$\beta_{136}$=0
$H_1$: does not equal to zero

the Akaike Information Criterion (AIC) is used to test the goodness of fit of $y^5$ versus $y^6$. The AIC test presents the fifth-order polynomial model (with AIC -212918 ) has a lower value than the sixth-order polynomial model (with AIC -212908). I therefore conclude that the fifth-order polynomial of $y$ is sufficient to capture the curvature of the Engel curves.[23] Interestingly, Zhen et al. (2014) also find that a fifth order polynomial is appropriate in their analysis of household food purchase data from the 2006 Nielsen Homescan panel.

### 2.4.4. *Price Elasticities*

Since the EASI demand model is generated from Hicksian demand functions, the derived elasticities are compensated demand elasticities.[24] Following Yen et al. (2012), the price elasticity from a censored demand system is:

$$\varepsilon_{ij}^{h} = \frac{1}{\overline{w_i}} \widehat{\Phi}_{\mathrm{i}} \times \alpha_{\mathrm{ij}} + \overline{\mathrm{w_j}} - \delta_{\mathrm{ij}} \qquad (11)$$

where $\delta_{ij}$ is the Kronecker delta with $\delta_{ii} = 1$ for the own price elasticities and $\delta_{ij} = 0$ for the cross price elasticities. I use the sample/subsample mean of the CDF as a measure of $\widehat{\Phi}_{\mathrm{i}}$ for elasticity estimation and $\overline{w_i}$ is estimated using the sample/subsample mean of the budget share for each food category.

Although compensated (Hicksian) demand elasticities are directly obtained from the EASI demand estimation, to be comparable to most of the other literatures, the uncompensated (Marshallian) demand elasticities are calculated through the Slutsky equation: $\varepsilon_{ij}^{h} = \varepsilon_{ij}^{m} + \eta_i \overline{w}_j$, where $\eta_i$ is the expenditure elasticity. Tables

[23] In this study, I compare the estimation of LA/AIDS, approximate QUAIDS generated by Blundell *et al.* (1993), and approximate EASI demands. Numerically, the major difference among the three is the inclusion of higher order polynomial of $y$. The LA/AIDS is linear in log real expenditure (y), approximate QUAIDS contains a quadratic expression of y, and the approximate EASI includes a fifth-order polynomial of $y$.

[24] This is quite different from traditional demand system estimation (i.e., AIDS or QUAIDS), since the latter is derived from the Mashallian demand .

2.3(a)-(c) report the estimated uncompensated price elasticities varied by income tercile. All the own price elasticities are negative and significant. Our results are not strictly comparable to the prior literature because the estimates can vary depending on different aggregation schemes, estimation techniques, theoretical restrictions on the demand model, types of data employed (i.e., time series vs. cross-sectional data), and the period covered. I find low income households are significantly more sensitive than high income households to own price changes for meat, fish, dairy, eggs, bakery, cereals and pasta, fruits, vegetables, oil, salt-fat products, sugar-fat products, and prepared meals, but less sensitive to own price changes for SSBs.

It is worthwhile noting some differences and similarities to some previous studies in the large literature estimating food demand elasticities. Table 2.4 presents uncompensated own price elasticities as reported in prior research using Canadian or U.S. data. Overall, most of our elasticity estimates are within the range of previous estimates based on two-step estimation presented in Yen et al. (2003) for meat, fish, bakery, cereal and pasta, fruits, vegetables, and SSBs. However, the elasticities of fat and oil and dairy are larger than those reported in previous studies. One possible explanation for this difference is that in this chapter, food categories are assigned based on food nutrient contents according to the Health Canada Canadian Nutrient File (2010). I separate ice-cream and butter from dairy products, and group them into sugar-fat products and fat and oil, respectively. Most empirical studies find butter has an elastic demand. Once it is classified into fat and oil, it makes the own-price elasticity of fat and oil higher than before. In terms of methodology, I use a two-step censored approximate EASI demand system which is different from the other studies.

Table 2.3 (a). *Uncompensated Price Elasticity for Low Income Group*

| | Fish | Dairy | Egg | Bakery | Cereal | Fruits | Vegetables | Oil | SSBs | Salt-fat | Sugar-fat | Prepared | Meat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Meat | -1.097 | -0.297 | -0.001 | -0.247 | -0.067 | -0.058 | -0.100 | -0.161 | -0.163 | -0.088 | -0.025 | -0.050 | -0.152 |
| | (0.021) | (0.081) | (0.029) | (0.093) | (0.038) | (0.057) | (0.041) | (0.037) | (0.078) | (0.036) | (0.088) | (0.059) | (0.064) |
| Fish | 0.151 | -1.294 | 0.105 | 0.063 | 0.134 | -0.010 | 0.003 | 0.144 | 0.194 | 0.138 | 0.122 | 0.057 | 0.024 |
| | (0.022) | (0.100)) | (0.022) | (0.100) | (0.035) | (0.045) | (0.034) | (0.031) | (0.071) | (0.024) | (0.083) | (0.046) | (0.051) |
| Dairy | 0.046 | -0.174 | -1.127 | -0.146 | -0.099 | -0.087 | -0.016 | 0.087 | -0.043 | 0.003 | -0.052 | 0.009 | -0.103 |
| | (0.020) | (0.055) | (0.032) | (0.062) | (0.026) | (0.039) | (0.028) | (0.026) | (0.054) | (0.025) | (0.060) | (0.040) | (0.045) |
| Egg | 0.171 | 0.037 | 0.116 | -0.933 | 0.067 | 0.053 | 0.123 | 0.084 | 0.009 | 0.054 | 0.086 | 0.078 | -0.003 |
| | (0.012) | (0.045) | (0.011) | (0.163) | (0.021) | (0.025) | (0.020) | (0.018) | (0.051) | (0.011) | (0.062) | (0.023) | (0.026) |
| Bakery | 0.035 | -0.045 | -0.054 | -0.225 | -0.782 | 0.006 | 0.029 | -0.052 | -0.209 | -0.019 | -0.094 | 0.020 | -0.161 |
| | (0.021) | (0.068) | (0.021) | (0.089) | (0.045) | (0.043) | (0.031) | (0.029) | (0.068) | (0.024) | (0.077) | (0.043) | (0.047) |
| Cereal | 0.170 | -0.067 | 0.098 | 0.028 | 0.120 | -1.293 | 0.096 | 0.031 | -0.066 | 0.093 | 0.064 | 0.090 | -0.027 |
| | (0.016) | (0.048) | (0.017) | (0.061) | (0.024) | (0.054) | (0.025) | (0.023) | (0.047) | (0.019) | (0.058) | (0.035) | (0.038) |
| Fruits | 0.011 | -0.303 | 0.008 | 0.001 | 0.024 | -0.039 | -0.838 | -0.006 | 0.035 | 0.034 | -0.121 | -0.136 | -0.096 |
| | (0.023) | (0.070) | (0.023) | (0.091) | (0.033) | (0.047) | (0.049) | (0.032) | (0.071) | (0.027) | (0.081) | (0.047) | (0.051) |
| Vegetables | 0.012 | -0.001 | 0.123 | -0.114 | -0.025 | -0.121 | 0.026 | -0.999 | -0.100 | 0.050 | -0.112 | 0.048 | -0.159 |
| | (0.019) | (0.059) | (0.020) | (0.076) | (0.028) | (0.041) | (0.029) | (0.4) | (0.059) | (0.023) | (0.067) | (0.040) | (0.044) |
| Oil | 0.172 | 0.137 | 0.140 | -0.012 | 0.047 | -0.012 | 0.146 | 0.078 | -1.209 | 0.059 | 0.025 | 0.002 | -0.018 |
| | (0.016) | (0.054) | (0.017) | (0.085) | (0.027) | (0.033) | (0.027) | (0.024) | (0.093) | (0.017) | (0.066) | (0.033) | (0.036) |
| SSBs | 0.100 | 0.062 | 0.091 | -0.061 | 0.051 | 0.051 | 0.095 | 0.086 | -0.033 | -1.196 | -0.109 | -0.030 | 0.002 |
| | (0.013) | (0.036) | (0.014) | (0.037) | (0.017) | (0.025) | (0.18) | (0.016) | (0.033) | (0.032) | (0.041) | (0.028) | (0.030) |
| Salt-fat | 0.201 | 0.091 | 0.134 | 0.127 | 0.089 | 0.083 | 0.080 | 0.070 | 0.030 | 0.016 | -1.244 | 0.053 | -0.014 |
| | (0.019) | (0.064) | (0.019) | (0.107) | (0.031) | (0.041) | (0.031) | (0.028) | (0.068) | (0.021) | (0.113) | (0.038) | (0.043) |
| Sugar-fat | 0.149 | -0.008 | 0.120 | 0.075 | 0.106 | 0.076 | 0.016 | 0.108 | -0.069 | 0.012 | 0.009 | -1.157 | -0.041 |
| | (0.018) | (0.052) | (0.018) | (0.059) | (0.024) | (0.036) | (0.026) | (0.024) | (0.049) | (0.022) | (0.056) | (0.057) | (0.039) |
| Prepared | 0.162 | -0.024 | 0.112 | -0.110 | 0.039 | -0.017 | 0.084 | 0.022 | -0.071 | 0.077 | -0.069 | -0.009 | -0.829 |
| | (0.021) | (0.062) | (0.022) | (0.071) | (0.028) | (0.042) | (0.031) | (0.028) | (0.058) | (0.025) | (0.068) | (0.042) | (0.069) |

Note: Standard errors are in parentheses.

Table 2.3 (b). *Uncompensated Price Elasticity for Medium Income Group*

| | Meat | Fish | Dairy | Egg | Bakery | Cereal | Fruits | Vegetables | Oil | SSBs | Salt-fat | Sugar-fat | Prepared |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Meat | -1.034 | -0.232 | 0.006 | -0.065 | -0.074 | -0.219 | -0.167 | -0.248 | 0.015 | -0.001 | -0.171 | -0.047 | -0.200 |
| | (0.036) | (0.070) | (0.029) | (0.089) | (0.036) | (0.053) | (0.037) | (0.036) | (0.082) | (0.037) | (0.078) | (0.053) | (0.060) |
| Fish | 0.179 | -1.091 | 0.123 | -0.001 | 0.089 | -0.099 | 0.115 | 0.069 | 0.141 | 0.083 | 0.074 | 0.022 | -0.098 |
| | (0.021) | (0.078) | (0.022) | (0.086) | (0.032) | (0.044) | (0.032) | (0.030) | (0.077) | (0.027) | (0.074) | (0.042) | (0.047) |
| Dairy | 0.069 | -0.136 | -0.971 | -0.152 | -0.057 | -0.169 | -0.045 | 0.060 | -0.024 | 0.014 | -0.060 | -0.175 | -0.151 |
| | (0.018) | (0.047) | (0.028) | (0.060) | (0.024) | (0.035) | (0.025) | (0.025) | (0.055) | (0.025) | (0.053) | (0.036) | (0.040) |
| Egg | 0.193 | 0.013 | 0.108 | -0.480 | 0.078 | -0.007 | 0.085 | 0.076 | 0.003 | 0.064 | 0.009 | 0.022 | 0.048 |
| | (0.009) | (0.029) | (0.010) | (0.147) | (0.017) | (0.022) | (0.016) | (0.015) | (0.044) | (0.010) | (0.051) | (0.017) | (0.021) |
| Bakery | 0.045 | -0.139 | -0.023 | -0.183 | -0.698 | 0.018 | -0.024 | -0.051 | -0.182 | -0.093 | -0.140 | 0.010 | -0.147 |
| | (0.020) | (0.055) | (0.021) | (0.086) | (0.040) | (0.042) | (0.030) | (0.029) | (0.070) | (0.024) | (0.071) | (0.038) | (0.044) |
| Cereal | 0.135 | -0.137 | 0.063 | -0.119 | 0.129 | -1.013 | 0.078 | 0.094 | -0.066 | 0.063 | 0.034 | 0.033 | 0.024 |
| | (0.015) | (0.039) | (0.015) | (0.058) | (0.022) | (0.047) | (0.022) | (0.021) | (0.049) | (0.017) | (0.048) | (0.028) | (0.032) |
| Fruits | -0.016 | -0.108 | -0.024 | -0.183 | -0.035 | -0.092 | -0.731 | 0.039 | -0.080 | -0.007 | -0.142 | -0.092 | -0.145 |
| | (0.022) | (0.059) | (0.023) | (0.088) | (0.032) | (0.045) | (0.046) | (0.031) | (0.075) | (0.027) | (0.073) | (0.042) | (0.049) |
| Vegetables | -0.012 | -0.145 | 0.107 | -0.150 | -0.016 | -0.016 | 0.077 | -1.018 | -0.032 | 0.057 | -0.128 | -0.023 | -0.068 |
| | (0.019) | (0.051) | (0.020) | (0.074) | (0.027) | (0.039) | (0.027) | (0.038) | (0.064) | (0.024) | (0.062) | (0.037) | (0.042) |
| Oil | 0.201 | 0.078 | 0.128 | -0.023 | 0.050 | -0.019 | 0.094 | 0.093 | -1.094 | 0.043 | 0.017 | -0.012 | 0.027 |
| | (0.015) | (0.046) | (0.016) | (0.080) | (0.025) | (0.033) | (0.025) | (0.023) | (0.086) | (0.018) | (0.062) | (0.029) | (0.034) |
| SSBs | 0.151 | -0.021 | 0.101 | -0.002 | 0.007 | 0.013 | 0.074 | 0.093 | -0.036 | -1.134 | -0.103 | -0.030 | -0.031 |
| | (0.013) | (0.032) | (0.013) | (0.035) | (0.016) | (0.023) | (0.017) | (0.016) | (0.034) | (0.031) | (0.036) | (0.024) | (0.026) |
| Salt-fat | 0.176 | 0.047 | 0.128 | -0.006 | 0.075 | 0.060 | 0.083 | 0.068 | 0.025 | 0.016 | -1.042 | 0.057 | 0.021 |
| | (0.015) | (0.047) | (0.016) | (0.097) | (0.026) | (0.035) | (0.025) | (0.024) | (0.065) | (0.019) | (0.095) | (0.029) | (0.036) |
| Sugar-fat | 0.173 | -0.045 | 0.041 | -0.069 | 0.116 | 0.021 | 0.063 | 0.078 | -0.078 | 0.016 | 0.019 | -1.071 | -0.021 |
| | (0.016) | (0.043) | (0.017) | (0.052) | (0.022) | (0.031) | (0.022) | (0.022) | (0.048) | (0.021) | (0.046) | (0.045) | (0.035) |
| Prepared | 0.136 | -0.161 | 0.064 | 0.023 | 0.033 | 0.023 | 0.044 | 0.063 | -0.003 | 0.026 | -0.028 | -0.011 | -0.743 |
| | (0.019) | (0.050) | (0.020) | (0.066) | (0.027) | (0.037) | (0.027) | (0.027) | (0.059) | (0.024) | (0.059) | (0.036) | (0.061) |

Note: Standard errors are in parentheses

Table 2.3 (c). *Uncompensated Price Elasticity for High Income Group*

| | Meat | Fish | Dairy | Egg | Bakery | Cereal | Fruits | Vegetables | Oil | SSBs | Salt-fat | Sugar-fat | Prepared |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Meat | -1.011 | -0.280 | -0.032 | -0.329 | -0.183 | -0.094 | -0.027 | -0.105 | -0.132 | -0.066 | -0.377 | -0.087 | -0.229 |
| | (0.038) | (0.068) | (0.030) | (0.111) | (0.037) | (0.060) | (0.038) | (0.036) | (0.088) | (0.039) | (0.087) | (0.055) | (0.063) |
| Fish | 0.159 | -0.716 | 0.121 | -0.211 | 0.127 | -0.165 | 0.037 | 0.114 | -0.198 | 0.109 | -0.141 | -0.030 | -0.057 |
| | (0.021) | (0.075) | (0.023) | (0.100) | (0.033) | (0.050) | (0.031) | (0.029) | (0.076) | (0.027) | (0.082) | (0.042) | (0.050) |
| Dairy | 0.068 | -0.108 | -0.846 | -0.275 | -0.080 | -0.200 | -0.043 | 0.005 | -0.063 | -0.001 | -0.150 | -0.101 | -0.163 |
| | (0.019) | (0.045) | (0.027) | (0.072) | (0.025) | (0.040) | (0.025) | (0.024) | (0.059) | (0.025) | (0.060) | (0.036) | (0.041) |
| Egg | 0.184 | -0.030 | 0.097 | -0.461 | 0.045 | -0.022 | 0.107 | 0.107 | 0.052 | 0.070 | 0.155 | 0.051 | 0.029 |
| | (0.010) | (0.028) | (0.011) | (0.168) | (0.018) | (0.026) | (0.017) | (0.016) | (0.050) | (0.011) | (0.066) | (0.019) | (0.022) |
| Bakery | 0.013 | -0.049 | -0.040 | -0.392 | -0.541 | -0.093 | -0.040 | -0.030 | -0.044 | -0.097 | -0.171 | -0.035 | -0.096 |
| | (0.019) | (0.050) | (0.020) | (0.102) | (0.040) | (0.045) | (0.028) | (0.026) | (0.073) | (0.023) | (0.077) | (0.037) | (0.043) |
| Cereal | 0.196 | -0.142 | 0.065 | -0.162 | 0.082 | -0.958 | 0.033 | 0.059 | -0.086 | 0.097 | 0.147 | 0.057 | -0.005 |
| | (0.015) | (0.038) | (0.016) | (0.070) | (0.022) | (0.049) | (0.021) | (0.020) | (0.052) | (0.018) | (0.058) | (0.029) | (0.033) |
| Fruits | 0.105 | -0.216 | -0.004 | -0.132 | -0.038 | -0.224 | -0.784 | -0.042 | -0.150 | 0.013 | -0.141 | -0.113 | -0.160 |
| | (0.022) | (0.055) | (0.023) | (0.106) | (0.032) | (0.050) | (0.043) | (0.029) | (0.078) | (0.027) | (0.081) | (0.043) | (0.049) |
| Vegetables | 0.065 | -0.070 | 0.045 | -0.086 | -0.018 | -0.143 | -0.034 | -0.945 | -0.007 | -0.015 | -0.153 | -0.073 | -0.067 |
| | (0.019) | (0.048) | (0.020) | (0.091) | (0.028) | (0.043) | (0.027) | (0.035) | (0.068) | (0.024) | (0.071) | (0.038) | (0.043) |
| Oil | 0.188 | -0.086 | 0.118 | 0.063 | 0.100 | -0.034 | 0.079 | 0.115 | -0.700 | 0.062 | -0.047 | 0.031 | -0.012 |
| | (0.014) | (0.038) | (0.015) | (0.090) | (0.024) | (0.034) | (0.022) | (0.021) | (0.082) | (0.016) | (0.064) | (0.027) | (0.031) |
| SSBs | 0.159 | 0.032 | 0.110 | 0.012 | 0.019 | 0.060 | 0.097 | 0.073 | 0.008 | -1.222 | -0.126 | -0.051 | -0.058 |
| | (0.013) | (0.029) | (0.013) | (0.041) | (0.015) | (0.025) | (0.016) | (0.015) | (0.034) | (0.033) | (0.043) | (0.024) | (0.029) |
| Salt-fat | 0.160 | -0.058 | 0.111 | 0.287 | 0.072 | 0.145 | 0.098 | 0.085 | -0.044 | 0.011 | -1.003 | 0.070 | 0.062 |
| | (0.016) | (0.046) | (0.018) | (0.132) | (0.028) | (0.042) | (0.026) | (0.024) | (0.072) | (0.022) | (0.112) | (0.032) | (0.037) |
| Sugar-fat | 0.166 | -0.078 | 0.070 | -0.005 | 0.079 | 0.028 | 0.041 | 0.055 | -0.022 | -0.020 | 0.020 | -0.958 | 0.005 |
| | (0.016) | (0.038) | (0.017) | (0.063) | (0.022) | (0.035) | (0.022) | (0.021) | (0.049) | (0.020) | (0.052) | (0.046) | (0.035) |
| Prepared | 0.139 | -0.099 | 0.054 | -0.068 | 0.059 | -0.033 | 0.031 | 0.077 | -0.098 | -0.014 | 0.024 | 0.021 | -0.740 |
| | (0.020) | (0.051) | (0.021) | (0.081) | (0.028) | (0.045) | (0.028) | (0.027) | (0.064) | (0.027) | (0.067) | (0.039) | (0.064) |

Note: Standard errors are in parentheses

Table 2.4. *Results of uncompensated own-price elasticities of demand from other studies*

| | Hassan et al(1976) | Moschini et al (1993) | Pomboza et al (2005) | Lambert et al (2006) | Huang et al (2000) | Yen et al (2003) | | | Reed et al (2005) | Okrent et al. (2011) | Current Estimates (2015)[25] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Publication | AAFC report | AAFC report | AAFC report | Agribusiness | USDA report | AJAE | | | AJAE | AJAE | |
| Data | Canadian Time series(years) | Canadian Time series (years) | Canadian FES 2001 | Canadian FES 1996 | U.S. NFCS[26] (1987) | U.S. NFSPS (1997) | | | U.S. CES (1982-2000) | U.S. BEA(1960-2009)[27] | Canadian FES 2001 |
| Model Specification | Utility Maximization | AIDS | Modified AIDS | QUAIDS | Modified AIDS | QML[28] | SML[29] | TS[30] | GCCT[31] | NBR[32] | EASI |
| **Meat** | | | | | | | | | -0.61 | -0.40 | -1.01 |
| Beef | -0.85 | -0.41 | -0.45 | -0.95 | -0.35 | -0.73 | -0.75 | -0.71 | | | |
| Pork | -0.95 | -0.56 | -0.68 | -1.05 | -0.69 | -1.09 | -1.07 | -0.89 | | | |
| Poultry | | -0.68 | -0.81 | -1.05 | -0.64 | -0.82 | -0.84 | -0.77 | | | |
| *Chicken* | -0.56 | | | | | | | | | | |
| *Turkey* | -1.09 | | | | | | | | | | |
| Fish | -0.79 | -0.58 | -0.10 | -0.66 | -0.39 | -1.13 | -1.15 | -0.65 | | | -1.12 |
| Other meat | | | -0.80 | -0.89 | -0.36 | -0.75 | -0.76 | -0.52 | | | |
| *Lamb* | -1.87 | | | | | | | | | | |
| *Veal* | -2.59 | | | | | | | | | | |
| **Dairy** | | | -0.88 | | -0.80 | -0.73 | -0.75 | -0.70 | -0.86 | | -1.04[33] |
| Milk | -0.44 | | | | | | | | | -0.91 | |

[25] Using aggregated data
[26] Nationwide Food Consumption Survey
[27] Bureau of Economic Analysis
[28] Quasi maximum likelihood
[29] Simulated maximum likelihood
[30] Two-step estimation
[31] Generalized composite commodity theorem
[32] National bureau research
[33] Cheese, Milk, Yogurt, and other dairy products. Butter and ice-cream are excluded.

| | Hassan et al(1976) | Moschini et al (1993) | Pomboza et al (2005) | Lambert et al (2006) | Huang et al (2000) | Yen et al (2003) | | | Reed et al (2005) | Okrent et al. (2011) | Current Estimates (2015)[25] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cheese | -0.91 | | | | | | | | | | |
| Other Dairy | | | | | | | | | | | |
| Butter | -0.86 | | | | | | | | | | |
| **Eggs** | -0.12 | | -0.35 | | -0.06 | -0.59 | -0.66 | -0.61 | | -0.73 | -0.67 |
| **Bakery and Cereal** | | | | | | | | | | -0.93 | |
| Bakery | | -0.37 | -0.43 | | | | | | | | -0.80 |
| *Bread* | | | | | -0.35 | -0.40 | -0.41 | -0.36 | | | |
| Cereal and Pasta | | | -0.7 | | | | | | | | -1.12 |
| *Cereal* | -0.20 | | | | -0.55 | -0.74 | -0.75 | -0.72 | | | |
| **Fruit and Vegetable** | | | | | | -0.71 | -0.74 | -0.73 | -0.98 | -0.58 | |
| Fruit | | | -0.84 | | -0.72 | | | | | | -0.85 |
| *Fresh fruit* | -0.45 | -0.47 | | | | | | | | | |
| *Processed fruits* | -0.75 | -0.16 | | | | | | | | | |
| Vegetable | | | -0.65 | | -0.72 | | | | | | -1.09 |
| *Fresh Vegetable* | -0.24 | -0.35 | | | | | | | | | |
| *Processed Vegetables* | -0.32 | -0.31 | | | | | | | | | |
| **Fat and Oil** | | -0.12 | -0.22 | | -0.40 | -0.58 | -0.60 | -0.44 | | | -1.10[34] |
| **SSBs** | -0.37 | -0.20 | -1.17 | | | -1.03 | -1.02 | -1.01 | | -0.77 | -1.27 |
| **Sugar - fat products** | | | | | | | | | | | -1.16 |
| **Salt-fat products** | | | | | | | | | | | -1.19 |
| **Prepared meals** | | | | | | | | | | | -0.88[35] |
| **Food away from home** | | -0.55 | | | | | | | -0.69 | -0.55 | |
| **Non food** | | -0.96 | | | | | | | -0.86 | -0.94 | |

34 Includes margarine, lard, shortening, cooking oil, and butter
35 Includes frozen dinner and soup.

In terms of cross-price elasticities, when there is a large degree of substitutability (cross price elasticity is positive and significant) among foods, consumers will tend to switch from unhealthy food (SSBs, salt-fat products, sugar-fat products, and prepared meals) to healthy food (dairy, fruits, and vegetables). However, almost half of the cross-price elasticities among foods are small and are statistically insignificant even at the 10% level. Although a fat tax decreases the consumption of unhealthy food, the small cross-price elasticities imply a fat tax will have little impact on food substitution. More details will be discussed in the next section.

### 2.4.5. *Nutrient Elasticities*

Nutrient elasticites are calculated following the approach of Huang (1996) and are defined as the percentage change in nutrient consumption with respect to a one percent change in food prices. The nutrient elasticity is expressed as:

$$Nut_{lj} = \omega_{li} * \varepsilon_{ij}^{M} \qquad (12)$$

where $l = 1, \dots, L$ represents for the nutrient of interest, $i, j = 1, \dots, N$ represents for food categories, and $\omega_{li}$ represents the contribution of the *i*th food to the *l*th nutrient. The uncompensated price elasticity for *i*th food with respect to the *j*th price change is $\varepsilon_{ij}^{M}$ (with $i = j$ represents for the own price elasticity). The nutrient elasticity therefore takes into account the fact that a change in a particular food price will affect all food quantities demanded through the interdependent demand relationships, and thus cause a simultaneous change in the levels of nutrient availability.

The Health Canada Commodity Nutrient File (CNF) (2010) is used to quantify nutrient intake, including calorie, protein, sugar, fibre, fat, saturated fat, and sodium, associated with the 13 food groups used in this analysis. One departure in this chapter is that the nutrient contents of each food category are allowed to vary by income tercile. Nutrient contents of each category of food under different income terciles are able to be calculated using the CNF jointly with the FES. It is reasonable to assume that even for the same category of food, higher income families might purchase food with higher quality, including higher protein levels, lower saturated fat, or lower sodium. Therefore, the nutritient contents for a specific category of food may be different across terciles. For example, for meat consumption, the higher income households might consume more meat containing higher protein and lower fat (i.e., beef and veal). Whereas, the lower income households might consume more meat with a lower price and poorer quality (i.e., ground pork). Therefore, even for the same food category, the nutrient contents vary by income terciles. Together with the FES, the nutrient elasticities across income groups are estimated.

Table 2.5 displays the nutrient elasticities across income groups.[36] Consistent with Huang and Lin (2000), Beatty and LaFrance (2005), and Allais et al. (2012), the nutrient elasticities are inelastic. In this research, calories and six major nutrients are selected, including protein, sugar, fiber, fat, saturated fat, and sodium. As shown in Table 2.5, increasing the price of any food category decreases total energy consumption for medium and high income households. For low income households, increasing the price of any food category decreases energy consumption, with the exception of fish.

[36] When calculating nutrient elasticities, price elasticities with insignificant *p-value* is treated as zero.

Table 2.5. *Nutrient Elasticities across Income Groups*

| | Meat | Fish | Dairy | Egg | Bakery | Cereal& Pasta | Fruits | Vegetables | Oil | SSBs | Salt-fat | Sugar-fat | Prepared |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Low income*** | | | | | | | | | | | | | |
| Kcal | -0.228 | 0.088 | -0.147 | -0.080 | -0.167 | -0.074 | -0.070 | -0.016 | -0.073 | -0.016 | -0.046 | -0.013 | -0.027 |
| Protein | -0.447 | 0.060 | -0.213 | 0.110 | -0.099 | -0.020 | -0.035 | 0.006 | 0.106 | -0.006 | 0.014 | -0.040 | -0.027 |
| Sugar | -0.069 | 0.077 | -0.183 | 0.087 | -0.102 | 0.072 | -0.228 | 0.028 | 0.084 | -0.289 | -0.02 | -0.164 | -0.006 |
| Fibre | -0.096 | 0.066 | -0.012 | 0.075 | -0.145 | -0.190 | -0.176 | -0.035 | 0.061 | 0.01 | -0.052 | -0.046 | -0.077 |
| Fat | -0.362 | 0.125 | -0.167 | 0.077 | -0.144 | 0.054 | -0.016 | -0.023 | -0.312 | 0.002 | -0.033 | -0.069 | -0.033 |
| Satfat | -0.350 | 0.120 | -0.288 | 0.090 | -0.122 | 0.083 | -0.025 | 0.002 | -0.198 | 0.001 | -0.012 | -0.074 | -0.028 |
| Na | -0.308 | 0.087 | -0.213 | 0.087 | -0.249 | 0.054 | -0.022 | -0.007 | 0.061 | -0.001 | -0.037 | -0.021 | -0.112 |
| ***Medium income*** | | | | | | | | | | | | | |
| Kcal | -0.080 | -0.074 | -0.038 | -0.068 | -0.152 | -0.063 | -0.081 | -0.015 | -0.069 | -0.024 | -0.035 | -0.020 | -0.012 |
| Protein | -0.062 | 0.092 | -0.019 | 0.096 | -0.082 | 0.075 | -0.043 | -0.012 | 0.111 | 0.002 | -0.004 | -0.061 | -0.033 |
| Sugar | -0.075 | 0.080 | -0.043 | 0.067 | -0.110 | 0.066 | -0.207 | 0.048 | 0.065 | -0.29 | -0.014 | -0.16 | -0.026 |
| Fibre | -0.174 | 0.033 | -0.052 | 0.055 | -0.134 | 0.063 | -0.182 | 0.011 | 0.054 | -0.006 | -0.049 | -0.053 | -0.057 |
| Fat | -0.033 | 0.114 | -0.006 | 0.079 | -0.124 | 0.061 | -0.023 | -0.010 | 0.081 | -0.001 | -0.052 | -0.086 | -0.02 |
| Satfat | -0.025 | 0.118 | -0.005 | 0.090 | -0.098 | -0.066 | -0.027 | 0.026 | 0.095 | 0.003 | -0.026 | -0.098 | -0.026 |
| Na | -0.076 | 0.078 | -0.030 | 0.086 | -0.220 | 0.079 | -0.034 | 0.010 | 0.086 | -0.01 | -0.045 | -0.031 | -0.093 |
| ***High income*** | | | | | | | | | | | | | |
| Kcal | -0.066 | -0.028 | -0.152 | -0.075 | -0.121 | -0.062 | -0.103 | -0.010 | -0.016 | -0.032 | -0.04 | -0.051 | -0.010 |
| Protein | -0.057 | 0.052 | -0.181 | 0.095 | -0.084 | 0.093 | -0.020 | 0.014 | 0.106 | 0.004 | -0.008 | -0.058 | -0.039 |
| Sugar | -0.048 | 0.063 | -0.143 | 0.078 | -0.091 | 0.054 | -0.234 | -0.006 | 0.071 | -0.313 | -0.006 | -0.156 | -0.025 |
| Fibre | -0.089 | 0.022 | -0.076 | 0.072 | -0.106 | 0.040 | -0.234 | -0.032 | 0.066 | -0.009 | -0.03 | -0.057 | -0.06 |
| Fat | -0.049 | 0.014 | -0.166 | 0.086 | -0.074 | -0.064 | -0.039 | 0.010 | -0.088 | 0.013 | -0.084 | -0.066 | -0.04 |
| Satfat | -0.035 | 0.040 | -0.260 | 0.090 | -0.063 | 0.067 | -0.034 | 0.019 | -0.044 | 0.014 | -0.051 | -0.076 | -0.041 |
| Na | -0.107 | 0.069 | -0.209 | 0.077 | -0.181 | 0.080 | -0.023 | 0.008 | 0.080 | -0.009 | -0.05 | -0.032 | -0.093 |

### 2.5. Simulation of Food Policies

In this section I present simulation results, from both economic and health perspectives, for the following four potential policies:

- A 10% subsidy on consumption of fruits and vegetables
- A 10% fat tax on SSBs, salt-fat products, sugar-fat products, and prepared meals[37]
- Revenues from the 10% fat tax are returned to each household as a lump-sum transfer
- Revenues from the 10% fat tax are used to subsidise fruit and vegetable purchases

For the last two food policies, I assume the government follows a revenue-neutral scenario. That is, the collected fat tax revenue is fully used to fund either a lump-sum transfer or to subsidise fruit and vegetable purchases.

#### 2.5.1. *Welfare effects*

*A. Tax incidence measures*

Three different measures of tax/subsidy incidence are used to evaluate the welfare impacts of the four food policies: (1) compensating variation (CV), (2) change in consumer surplus (CS) using uncompensated elasticities by income tercile, and (3) change in consumer surplus using uncompensated elasicitities estimated from the whole sample.

CV is defined as the change in income required to keep a consumer's utility constant as a result of a price change. Since EASI demand systems are dual to cost functions, it is straightforward to estimate compensating variation, which can be expressed as:

$$CV_h = C_h(\boldsymbol{p}^{\boldsymbol{1}}, u, \boldsymbol{z}, \varepsilon) - C_h(\boldsymbol{p}^{\boldsymbol{0}}, u, \boldsymbol{z}, \varepsilon)$$

[37] Prepared meals usually contain high fat, calorie and sodium (Allais et.al.,2010).

$$= x_h \left( exp\left\{ \sum_{i=1}^{N} w_{ih} \, (lnp_{ih}^1 - lnp_{ih}^0) + \frac{1}{2} \sum_{i=1}^{N} \sum_{k=1}^{N} \alpha_{ik} \, (lnp_{ih}^1 - lnp_{ih}^0)^2 \right\} - 1 \right) \qquad (13)$$

for $i = 1, \ldots, N$ food categories and $h = 1, \ldots, H$ households, where $\mathbf{p^0} = (\mathrm{p_{ih}^0}, i = 1, \ldots, N; h = 1, \ldots, H\ )$ is the vector of prices before the tax and $\mathbf{p^1} = (\mathrm{p_{ih}^1}, i = 1, \ldots, N; h = 1, \ldots, H\ )$ is the vector of prices after the tax. The variable $C_h(\boldsymbol{p^0}, u, \boldsymbol{z}, \varepsilon)$ stands for the individual's cost of holding a certain utility level, $u$, with the food prices at $\mathbf{p^0}$, given household characteristics $\boldsymbol{z}$, and unobserved heterogeneity ε. $C_h(\boldsymbol{p^1}, u, \boldsymbol{z}, \varepsilon)$ is the new cost after the price change ($\mathbf{p^0} \rightarrow \mathbf{p^1}$), holding utility and all the other variables constant. The variable $w_{ih}$ is the budget share of food *i* and household *h* before tax.

Equation (13) calculates compensating variation due to the price changes, accounting for substitution effects across products. Therefore, the compensating variation for more than one price change will not equal the sum of the compensating variation for the price changes considered separately.

The change in consumer surplus measure using uncompensated elasticities can be expressed as

$$\Delta CS_h = \sum_{i=1}^{N} \left[ \left( 2 - \frac{\varepsilon_{ih}(p_{ih}^1 - p_{ih}^0)}{p_{ih}^0} \right) \times (p_{ih}^1 - p_{ih}^0) \times \frac{q_{ih}^0}{2} \right] \qquad (14)$$

where $\varepsilon_i$ is the uncompensated own price elasticity of food $i$; $p_{ih}^0$ is the price of food category *i* before the tax; $p_{ih}^1 = p_{ih}^0(1 + \tau_i)$ is the price after tax, where $\tau_i$ is the tax rate on food $i$; and $q_{ih}^0$ is the quantity of food $i$ consumed by household *h* before tax. I consider two separate cases: (1) elasticities varied across income terciles and (2) elasticities estimated using the whole sample. I assume linear demand curves. Compared with the compensating variation measure, though easier to estimate, the consumer surplus measure loses some accuracy, especially for large price changes or for simultaneous price changes.[38]

*B. Economic efficiency of food policies*

The economic efficiency of the various food policies is measured by their tax burdens, where the higher the tax burden, the less the efficiency.[39] The tax burden under each scenario is expressed as:

(1) Scenario 1: $TB = \frac{\sum_h M^A}{\sum_h^H I_h} \times 100\%$ (15)

(2) Scenario 2: $TB = \frac{\sum_h M^B}{\sum_h^H I_h} \times 100\%$ (16)

(3) Scenario 3: $TB = \frac{\sum_h (M^B + TR^{OECD})}{\sum_h^H I_h} \times 100\%$ (17)

(4) Scenario 4: $TB = \frac{\sum_h M^C}{\sum_h^H I_h} \times 100\%$ (18)

The variable $TB$ denotes the percentage tax burden. In this chapter $TB$ is estimated under each income tercile. The variable $I_h$ denotes family income of household $h$, and $H$ represents the total number of households in each tercile. The tax/subsidy incidences (CV, $\Delta CS$ using elasticities varied by income tercile, and $\Delta CS$ using elasticities estimated using the whole sample) is denoted as $M^j$, where the superscript *j* stands for different tax reforms with "A" representing the first scenario, "B" representing the second scenario, and "C" representing for the fourth scenario. For

[38] When more than one price changes, it is not path independent. More crucially, consumer surplus measure in fact assumes cross price elasticities equals to zero. However, Willig(1976) showed that for small price changes, the error caused by using Mashallian consumer surplus measurement instead of compensating variation is small and one can simply ignore it "without apology".

[39] The greater the magnitude (absolute value) of the tax burden, the less efficient the tax reform.

the third scenario, the lump-sum transfer is based on the OECD equivalence scale, written as $TR^{OECD}$. If $M^B + TR^{OECD} > 0$, it implies the household obtains a net transfer. If $M^B + TR^{OECD} < 0$, it implies the household suffers a net loss. The aggregated tax burden is measured as the sum of the burden across all three terciles, divided by the sum of total income of the whole sample.

*C. Progressivity of tax reforms*

Suits (1977) developed the Suits Index to measure the progressivity of one or more taxes. West et al. (2004) modified the Suits Index to evaluate revenue- neutral tax burdens. Like the Suits Index, the progressivity index developed by West et al. (2004) is used to evaluate the progressivity of a tax burden. This index is given by:

$$PIDX = \sum_{\zeta=1}^{3} \kappa_\zeta - \sum_{\zeta=1}^{3}\left[\left(-\kappa_\zeta + 2\sum_{\varrho=1}^{\zeta} \kappa_\varrho\right)\left(R_\zeta - R_{\zeta-1}\right)\right] \quad (19)$$

where PIDX represents for the progressivity index; $R_\zeta$ is tercile $\zeta$'s accumulated percent of total income and $\kappa_\zeta$ is the tax burden on tercile $\zeta$ as a fraction of total income for all terciles. This progressivity index has the same features as the Suits index—a positive value indicates a progressive tax, a negative value indicates a regressive tax, and zero indicates a "flat" tax.

When conducting simulations of food policies, most of the literature applies a small amount of value added tax or subsidy (i.e., Okrent and Alston, 2012; Allais, Bertail and Nichele, 2010). In practice, Australia introduced a 10% tax on soft drinks, confectionery, biscuits and bakery products in 2000. Therefore, in this chapter I hypothetically apply a 10% subsidy on fruits and vegetables, and a 10% fat tax on sugar-fat products, salt-fat products, SSBs, and prepared meals. Table 2.6 displays the results of the four food policies considered. I estimate the impacts of the four food policies on consumer welfare varied by income terciles. A subsidy financially benefits households whereas a tax imposes a burden on households. Following equations (15)-(18), the percentage tax burden is calculated as the tax incidence divided by household income. Therefore, a subsidy with positive incidence (a positive CV or a positive $\Delta CS$) will have a positive sign when the tax burden is calculated. A tax with a negative incidence (a negative CV or a negative $\Delta CS$) will lead to a negative tax burden in the calculation.

In general, the consumer surplus and the compensating variation measures yield similar results. The major differences between consumer surplus and compensating variation are: (1) the consumer surplus measure ignores the cross-price effects, and (2) the consumer surplus measure assumes a linear demand curve. These differences are small in our simulation analysis, since most of the substitution effects among food are small.

Table 2.6. *Incidence of food policies*

| | Tax burden varied by income tercile | | | Aggregate tax burden | Progressivity Index |
|---|---|---|---|---|---|
| | Low | Medium | High | | |
| *Subsidies on Fruits and Vegetables* | | | | | |
| Compensating variation | 0.595% | 0.285% | 0.181% | 0.262% | 0.047% |
| Consumer surplus (by tercile elasticities) | 0.602% | 0.289% | 0.183% | 0.265% | 0.047% |
| Consumer surplus (by aggregate elasticities) | 0.604% | 0.287% | 0. 183% | 0.264% | 0.048% |
| *Tax revenue discarded* | | | | | |
| Compensating variation | -0.441% | -0.225% | -0.134% | -0.198% | -0.045% |
| Consumer surplus (by tercile elasticities) | -0.433% | -0.222% | -0.132% | -0.196% | -0.044% |
| Consumer surplus (by aggregate elasticities) | -0.434% | -0.222% | -0.132% | -0.195% | -0.044% |
| *Recycled revenue used to provide lump-sum transfer to households (based on an OECD equivalence scale)* | | | | | |
| Compensating variation | 0.062% | -0.022% | -0.028% | -0.016% | 0.010% |
| Consumer surplus (by tercile elasticities) | 0.074% | -0.017% | -0.025% | -0.011% | 0.011% |
| Consumer surplus (by aggregate elasticities) | 0.073% | -0.017% | -0.025% | -0.011% | 0.011% |
| *Recycled revenue used to provide subsidies to fruits and vegetables* | | | | | |
| Compensating variation | -0.034% | -0.029% | -0.010% | -0.019% | -0.005% |
| Consumer surplus (by tercile elasticities) | -0.027% | -0.027% | -0.009% | -0.017% | -0.005% |
| Consumer surplus (by aggregate elasticities) | -0.029% | -0.027% | -0.008% | -0.017% | -0.005% |

A 10% subsidy on fruit and vegetable retail products causes the consumption of fruit and vegetables to increase. On average this policy increases the incomes of low, medium, and high income households by 0.595%, 0.285%, and 0.181% respectively. I find that a stand-alone subsidy on fruits and vegetables is most progressive with a positive progressivity index of 0.047%. This is due to the fact that the subsidy accounts for a greater share of income in lower income households relative to the other two groups.

Not surprisingly, a 10% fat tax with revenue discarded is regressive.[40] Under this policy scenario, the tax burden on low income households (-0.441%) is more than three times the burden on the high income households (-0.134%). The progressivity index of -0.045% indicates that this policy is the most regressive of the four policies considered.

Using the recycled revenue to provide a lump-sum transfer to households generates a different result. Under this policy, the income of low income households increases by 0.062%. In this case, for lower income households, the transfer they receive more than offsets the higher price of food. For the medium and high income households, however, the effect of higher food prices dominates, and so those households are made worse off. For medium income households the tax burden is -0.022%. The tax burden is highest for the high income households at -0.028%. Overall, a lump-sum transfer is progressive with a positive progressivity index of 0.010%.

Using the recycled revenue to subsidise fruits and vegetables increases incomes in all income groups relative to the scenario where revenue is discarded. The simulation results suggest that the revenue generated from a 10% fat tax on SSBs, salt-fat products, sugar-fat products and prepared meals can fund a 6.73% subsidy on fruit and vegetables.[41] Subsidies on fruits and vegetables generate a greater aggregate tax burden (-0.019%) than a lump-sum transfer (-0.016%). Using tax revenues to subsidise fruit and vegetable purchases generates more deadweight loss than directly transferring tax revenues to each household. Further, the progressivity index suggests that the use of a fruit and vegetable subsidy in conjunction with the fat tax is regressive (-0.005%), although this is small compared to the regressivity of the fat tax alone.

---

[40] In fact, a food tax whatever the amount is always regressive.
[41] The rest of the revenue goes to the deadweight loss.

In general, from an economic perspective, a subsidy on fruits and vegetables is the most pregressive policy, and it would potentially improve consumer welfare for all income groups at the expense of higher government costs. Among the rest of the food policies, a lump-sum transfer is the most economically efficient and progressive approach, followed by using collected revenues to subsidise fruits and vegetables. A stand-alone fat tax with collected revenue discarded is the least economically efficient and most regressive approach.

### 2.5.2. Health Impacts

The previous section demonstrates that different food policies generate different welfare impacts on households. In this section, I will focus on the impact of the four policies on nutrient intake. Table 2.7 reports the summary of calorie and major nutrient consumption using FES (2001) varied by income terciles. On average the individual consumption of calories is 1954 kcal/day (2044 kcal/day, 2081 kcal/day) for low (medium, high) income households.

Table 2.7. *Summary of Calorie and major nutrient consumption*

| | Kcal | Protein(g) | Sugar(g) | Fiber(g) | Fat(g) | Saturated Fat(g) | Sodium(mg) |
|---|---|---|---|---|---|---|---|
| Aggregate | 2027.96 | 79.18 | 90.93 | 16.89 | 82.26 | 28.35 | 2226.04 |
| Low income | 1954.17 | 74.80 | 83.22 | 15.65 | 81.55 | 27.35 | 2129.44 |
| Med income | 2044.19 | 79.30 | 91.15 | 17.09 | 82.43 | 28.04 | 2234.39 |
| High income | 2081.25 | 83.25 | 98.09 | 17.87 | 82.77 | 29.65 | 2309.78 |

Note: The summary data are from FES(2001)

Table 2.8 displays the percentage change in caloric intake and consumption of various nutrients as a consequence of the four food policies considered in this research. The distribution of impacts depends on the nature of revenue recycling.

Table 2.8. *Change of calorie and major nutrient consumption varied by income under each scenario (%)*

| (%) | Kcal | Protein | Sugar | Fiber | Fat | Saturated fat | Sodium |
|---|---|---|---|---|---|---|---|
| *Low* | | | | | | | |
| Tax | -1.51 | -0.51 | -3.29 | -2.55 | -1.25 | -1.04 | -1.71 |
| Subsidy | 0.93 | 0.89 | 2.77 | 4.38 | 0.44 | 0.05 | 0.94 |
| Recycled revenue subsidising F & V | -0.83 | 0.04 | -2.53 | 1.55 | -1.14 | -1.03 | -0.99 |
| Recycled revenue for lump-sum transfer | -1.51 | -0.51 | -3.29 | -1.55 | -1.25 | -1.04 | -1.71 |
| *Medium* | | | | | | | |
| Tax | -1.88 | -0.86 | -4.1 | -2.32 | -1.39 | -1.26 | -1.79 |
| Subsidy | 1.21 | 1.15 | 2.39 | 4.11 | 0.64 | 0.61 | 1.3 |
| Recycled revenue subsidising F & V | -1.09 | -0.07 | -3.29 | 1.11 | -1.04 | -0.94 | -0.84 |
| Recycled revenue for lump-sum transfer | -1.88 | -0.86 | -4.1 | -1.55 | -1.39 | -1.26 | -1.79 |
| *High* | | | | | | | |
| Tax | -2.13 | -0.94 | -4.1 | -1.08 | -1.39 | -1.26 | -1.79 |
| Subsidy | 1.43 | 0.79 | 3.0 | 5.01 | 0.49 | 0.47 | 1.08 |
| Recycled revenue subsidising F& V | -1.01 | -0.30 | -2.88 | 1.72 | -1.32 | -1.14 | -1.10 |
| Recycled revenue for lump-sum transfer | -2.13 | -0.94 | -4.1 | -1.55 | -1.39 | -1.26 | -1.79 |

A 10% fat tax on SSBs, salt-fat products, sugar-fat products, and prepared meals decreases total energy intake for low (medium, high) income households by 1.51% (1.88%, 2.13%). As a result, the fat tax decreases calorie consumption of high income households by 44.33/day, followed by a reduction in medium income households of 38.43/day, and a reduction in low income households of 29.51 /day. Further, the fat tax decreases protein, sugar, fat, saturated fat, and sodium consumption.

Compared with the other scenarios, if the primary goal is to reduce caloric intake, a fat tax is most effective. However, the tax on SSBs, salt-fat products, sugar-fat products, and prepared meals also decreases fiber intake: the 10% fat tax decreases fiber consumption by 2.55%, 2.32%, and 1.08% for low, medium, and high income households, respectively. These results suggest that the fat tax generates relatively small reductions in caloric intake and relatively large decreases in fiber consumption among the lower income households. This is due to different nutrient elasticities across income terciles. According to Table 2.5, low income households have relatively low calorie elasticities with respect to the SSBs, salt-fat products, sugar-fat products and prepared meals compared with medimn and high income households. Therefore, a price increase on SSBs, salt-fat products, sugar-fat products and prepared meals will have less impact on calorie reduction for low income families. However, low income households have relatively higher fiber elasticities for salt-fat products and prepared meals, when compared with medium and high income households. As a result, a price increase on SSBs, salt-fat products, sugar-fat products and prepared meals has a larger impact on fiber reduction for low income households.

A 10% subsidy on fruits and vegetables causes consumption of fruits and vegetables to increase. However, subsidies on fruits and vegetables increase energy intake and consumption of other nutrients. A reduction in the price of fruits and vegetables increases consumption of their complements and decreases consumption of their substitutes. For low income households, consumption of high calorie foods, such as meat, fish, dairy, eggs, and oils increases due to increased consumption of fruits and vegetables. Hence, a policy of subsidising fruits and vegetables at 10% would potentially increase calorie consumption by 18.17 kcal (24.73 kcal, 26.76 kcal) per day for an average adult in a low (medium, high) income household. In contrast to a food tax, a fruit and vegetable subsidy increases caloric intake.

A revenue-neutral scenario with the recycled revenue used to subsidise fruits and vegetables decreases household energy and nutrient consumption. This revenue-neutral scenario has two impacts. First, the tax decreases household energy and nutrient consumption by decreasing expenditures on unhealthy food. Second, as is the case with the pure fruit and vegetable subsidy, reducing the price of fruit and vegetables causes households to increase consumption of other foods thus increasing energy and nutrient consumption. As a result, the impact of food taxes in decreasing energy intake is not prominent.

A revenue- neutral scenario with recycled revenues providing a lump-sum transfer to each household is more complicated than the other scenarios. When recycled revenues are transferred to each household according to OECD equivalence scales, households use this money either on food or non-food products, or both. However, the FES simply contains household food expenditure with no records on expenditure on other non-food categories (i.e., durables, personal care, mortgage expenditure) Therefore, the exact marginal effect of changes in income on food consumption by income groups is not available. This issue can be addressed by using Statistics Canada's Survey of Household Spending (SHS). In 2001, the average percentage of income spent on food by low (medium, high) income households is 20.92% (11.13%, 6.42%). Therefore, the overall nutrient effects of a lump-sum transfer are estimated assuming that 20.92% (11.13%, 6.42%) of the transferred money is used for food expenditure for low (medium, high) income households. The simulation results indicate that a tax with a revenue-neutral lump-sum transfer decreases energy intake by 1.51% (1.88%, 2.13%) for low (medium, high) income households. The results are equivalent to a stand-alone fat tax. This is because the overall impact of the transferred money on calorie and nutrient intake is trivial—only 12 cents/day (6.6 cents/day, 3.9 cents/day) of the transferred money is used for food purchases for low (medium, high) income households, including both healthy and unhealthy food spending. As a result, a revenue-neutral scenario with a lump-sum transfer is no different from a stand- alone fat tax in terms of changing energy and nutrient consumption.

### 2.6. Conclusion

In this chapter, a two-step censored approximate EASI method is used to estimate the demand for thirteen types of food using cross-sectional data from Canada. I find that the two-step censored approximate EASI demand model provides a more accurate estimation than either the two-step LA/AIDS or approximate QUAIDS. It is a more flexible estimation method capturing different shapes of Engel curves of food.

I estimate own-price elasticities that vary by income tercile. For most of the food categories, high income households are less sensitive to food price changes when compared to low and medium income households. In terms of the cross-price elasticities, the substitution effects among most food categories are small and insignificant.

Ultimately, the simulation results show that when considering both economic and nutrient consumption impacts, if the goal of policymakers is simply to reduce caloric intake in Canada without increasing burdens on government resources, the preferred policy would be to use the recycled revenue from a fat tax to provide lump-sum transfers to households. From an economic perspective, this is the most progressive scenario (aside from a stand-alone fruit and vegetable subsidy), since low income households are left better off through the lump-sum transfer. From a health perspective, this tax reform decreases household calorie consumption. A 10% fat tax without recycling the revenue decreases household calorie consumption, but it is regressive and generates the greatest tax burden on low income households. A 10% subsidy on fruits and vegetables is the most progressive, but puts a strain on government resources and increases consumption of calories.

In this study, I have examined the efficiency of adopting a revenue- neutral food policy with collected fat taxes redistributed via a lump-sum transfer. Although the implementation of this revenue- neutral food policy is not complicated, it has not been applied in practice. Regarding energy/environmental policy, British Columbia's revenue- neutral carbon tax is a successful example of a revenue- neutral tax. The collected revenue is fully used to lower household income and corporate taxes, to support other programs promoting energy efficiency, and provide lump-sum rebates to agriculture (Rivers and Schaufele, 2014).

## REFERENCES


Allais, O., Bertail, P., and V. Nichele. 2010. The Effects of A Fat Tax on French Households' Purchases: A Nutritional Approach. *American Journal of Agricultural Economics* 92(1), 228-245.

Alderman, H., and D.E. Sahn. 1993. Substitution between Goods and Leisure in a Developing Country. *Amer. J. Agr. Econ.* 75: 875-83.

Banks, J., Blundell, R., and A. Lewbel. 1997.Quadratic engel curves and consumer demand. *Rev. Econ. Stat*. 79(4), 527–539

Becker, G., 2009. A Tax on Sodas? The Becker-Posner Blog http://www.beckerposner-blog.com/2009/05/a-tax-on-sodas-becker.html

Bento, A.M., Goulder, L.H. , Jacobsen , M.R., and R.H. vonHaefen**.** 2009. Distributional and Efficiency Impacts of Increased US Gasoline Taxes. *The American Economic Review* Vol. 99, No. 3,pp. 667-699

Bento, A.M., Goulder, L.H. , Jacobsen , M.R., and R.H. von Haefen**.** 2005.Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically Based Multi-Market Study. *The American Economic Review*, Vol. 95, No. 2, pp. 282-287

Brännlund, R. and J. Nordström. 2004. Carbon tax simulations using a household demand model.

*European Economic Review*. 48 (2004) 211 – 233

Blundell, R., Pashardes, P., and G. Weber. 1993.What do we learn about consumer demand patterns from micro data? *Am. Econ. Rev.* 83, 570–597

Blundell, R., Chen, X.H., and D. Kristensen. 2007. "Semi-nonparametric IV Estimation of Shape-Invariant Engel Curves." *Econometrica*, 75(6): 1613–69.

Brownell, K.D., Farley, T., Willett, W.C., Popkin, B.M., Chaloupka, F.J., Thompson, J.W., and D.S. Ludwig. 2009. The public health and economic benefits of taxing sugar-sweetened beverages. *New England Journal of Medicine* 361, 1599–1605.

Cash, S., and R. Lacanilao. 2007.Taxing Food to Improve Health: Economic Evidence and Arguments. *Agricultural and Resource Economics Review*, 36(2), 174-182.

Cash, B., Sunding, D., and D. Zilberman, 2006. Fat Taxes and Thin Subsidies: Prices, Diet, and Health Outcomes. *Food Economics*, 2, 167-174.

Cash, S., Goddard, E., and R. Lacanilao. 2007. Fat Taxes and Health Outcomes: An Investigation of Economic Factors Influencing Obesity in Canada. *Consumer and Market Demand Network Papers*, 6841.

Chaloupkal, F.J., Yurekli, A., and G. T. Fong. 2012.Tobacco taxes as a tobacco control strategy. *Tob Control* 2012;21:172-180 doi:10.1136/tobaccocontrol-2011-050417

Chouinard, H., Davis, D., LaFrance, J., and J. Perloff. 2007. Fat Taxes: Big Money for Small Change. *Forum for Health Economics & Policy*, 10(2), 2.

Deaton, Angus S. and John Muellbauer. 1980. "An Almost Ideal Demand System." *American Economic Review*, 70(3): 312–26.

Finkelstein, E.A., Zhen, C., Bilger, M., Nonnemaker, J., Farooqui, A.M., and J.E. Todd. 2013. Implications of a sugar-sweetened beverage (SSB) tax when substitutions to non-beverage items are considered. *Journal of Health Economics* 32 (2013) 219– 239

Hassan, Z. and S.R. Johnson.1976. Consumer demand for major food in Canada. Ottawa,

Ontario: Economics Branch, Agriculture Canada.

Health Canada. 2006. Healthy Eating. Ottawa: Health Canada, 2006. http://www.hc-sc.gc.ca/ahc-asc/branch-dirgen/hpfb-dgpsa/3kit-fiche/factsheet_fiches-info_05-eng.php (accessed 11.16.2014)

Huang, K. and B. Lin. 2000. Estimation of Food Demand and Nutrient Elasticities from Household Survey Data. United States Department of Agriculture. *Economic Research Service.*

*Technical Bulletin* No. 1887, August, 2000.

Heckman, J.J. 1976. The Common Structure of Sta-tistical Models of Truncation, Sample Selec-tion, and Limited Dependent Variables and A Simple Estimator for Such Models. *Annals Econ. and Soc. Meas*. 5(Fall 1976):475- 92.

Heien,D., and C.R.Wessells. 1990. Demand Systems Estimation with Microdata: A Censored Regression Approach. *Journal of Business and Economics Statistics* 8:365–71.

Kamerow, D. 2010. The case of the sugar sweetened beverage tax. *BMJ 2010; 341 doi: http://dx.doi.org/10.1136/bmj.c3719*

Kasteridis, P., Yen, S.T., and C. Fang. 2011. Bayesian Estimation of a Censored Linear Almost Ideal Demand System: Food Demand in Pakistan. *American Journal of Agricultural Economics.* Vol. 93, No. 5, 10.2011, p. 1374-1390

Lambert, R., Larue, B, Yélou, C, and G. Crine. 2006. Fish and meat demand in Canada: Regional differences and weak separability. *Agribusines* Volume 22, Issue 2, pages 175–199

Lewbel, A. and K. Pendakur. 2009. Tricks with Hicks: The EASI Demand System. *American Economic Review*, 99 (3), 827-863.

McAleer, M., M.C. Medeiros, and D. Slottje. 2008. A neural network demand system with heteroskedastic errors. *J. Econometrics* 147 , 359-371

Moschini, G. and D. Moro. 1993. A food demand system for Canada. Technical Report 1/93

prepared for Agriculture and Agri-food Canada. Ottawa, Ontario: Policy Branch.

Murphy, K. M, and R. H., Topel. 1985. Estimation and Inference in Two-Step Econometric Models. *Journal of Business & Economic Statistics* Vol. 3(4), pages 370-79.

Nordstrom, J., and L. Thunstrom. 2009. The impact of tax reforms designed to encourage healthier grain consumption. *Journal of Health Economics* 29, 622–634.

Nordstrom, J. and L.Thunstrom. 2011(a). Can targeted food taxes and subsidies improve the diet? Distributional effects among income groups. *Food Policy*, 36, 259-271.

Nordstrom, J. and L. Thunstrom. 2011(b). Economic policies for healthier food intake: The impact on different household categories. *European Journal of Health Economics*, Volume 12, Issue 2, April 2011, Pages 127-140

O'Donoghue, T., and M., Rabin. 2006. Optimal sin taxes. *Journal of Public Economics, 90(10-11)*, 1825-1849.

Okrent, A.M. and J.M. Alston. 2012. The Effects of Farm Commodity and Retail Food Policies on Obesity and Economic Welfare in the United States. *American Journal of Agricultural Economics* 94 (1): 611–646.

Pendakur, K. 1999. Semiparametric Estimates and Tests of Base-Independent Equivalence Scales. *Journal of Econometrics*, 88(1): 1–40.

Pomboza, R., and M. Mbaga .2007. The Estimation of *Food Demand* Elasticities in Canada. AAFC report.

Posner, R. 2009. A Soda or Calorie Tax to Reduce Obesity. The Becker-Posner

Blog http://www.becker-posner-blog.com/2009/05/a-soda-or-calorie-tax-toreduce-

obesity-posner.html ( accessed 11.27.2014)

Public Health Agency of Canada report. 2013. *Obesity in Canada*. Public Health Agency of Canada, 2011. http://www.phac-aspc.gc.ca/hp-ps/hl-mvs/oic-oac/ (accessed 11.16.2014)

Reed, A., Levedahl, J.W., and C. Hallahan. 2005. The Generalized Composite Commodity Theorem and Food Demand Estimation. *American Journal of Agricultural Economics* 87(2): pp. 28-37

Rivers, N., and B., Shaufele. 2014. The Effect of British Columbia's Carbon Tax on Agricultural Trade.http://pics.uvic.ca/sites/default/files/uploads/publications/Carbon%20Tax%20on%20Agricultural%20Trade_0.pdf (accessed 1.13.2015)

Smed, S. and Jensen, J., and S. Denver. 2007. Socio-economic characteristics and the effect of taxation as a health policy instrument. *Food Policy*, 32, 624-639.

Shonkwiler, J. S., and S. T.Yen. 1999. Two-Step Estimation of a Censored System of Equations. *American Journal of Agricultural Economics* 81(4): 972–982.

Statistics Canada, Health report. 2011(a). *Overweight and obesity in children and adolescents: Results from the 2009 to 2011 Canadian Health Measures Survey*. Ottawa: Statistics Canada, 2004. http://www.statcan.gc.ca/pub/82-003-x/2012003/article/11706-eng.htm (accessed 1.9.2015)

Statistics Canada, 2011(b). *Adult obesity prevalence in Canada and the United States.* Ottawa: Statistics Canada, 2011. http://www.statcan.gc.ca/pub/82-625-x/2011001/article/11411-eng.htm (accessed 1.9.2014)

Statistics Canada. Low Income Cutoffs and measurement. http://www.statcan.gc.ca/pub/75f0002m/2009002/tbl/tbl-5-eng.htm

Stafford, N. 2012. Denmark cancels "fat tax" and shelves "sugar tax" because of threat of job losses. *British Medical Journal* 2012;345:e7889 doi: 10.1136/bmj.e7889

Suits, D. 1977. Measurement of tax progressivity. The American Economic Review. 67, 747-752 .

Survey of Household Spending. 2001. Statistics Canada -public used microdata

The New York Times. 2012 (Novermber. 12). "Fat Tax" in Denmark Is Repealed After Criticism.

West, S., and R. C. Williams III. 2004. Estimates from a Consumer Demand System: Implications for the Incidence of Environmental Taxes. *Journal of Environmental Economics and Management* 47: 535–558.

World Health Organization. 2004. *Global strategy on diet, physical activity and health.* Geneva: WHO.

Yen, S. T., and B. Lin. 2006. A Sample Selection Approach to Censored Demand Systems. *American Journal of Agricultural* ec*onomics* 88 (3): 742–749.

Yen, S. T., B. Lin, and D. M. Smallwood. 2003. Quasi and Simulated Likelihood

Approaches to Censored Demand Systems: Food Consumption by Food Stamp Recipients in the United States. *American Journal of Agricultural Economics* 85(2): 458–478.

Zhen, C., Wohlgenant, M.K., Karns,  and S., P. Kaufman. 2011. Habit formation and demand for sugar-sweetened beverages. *American Journal of Agricultural Economics* 93, 175–193.

## CHAPTER 3

## Assessing the Impact of British Columbia Carbon Tax on Residential Natural Gas Consumption: A Synthetic Control Approach

ABSTRACT

I estimate the effects of British Columbia's (BC) carbon tax on per capita residential natural gas consumption using a newly developed statistical methodology for data-driven case studies—the synthetic control method. By applying the synthetic control method, a group of states/provinces against which BC's residential natural gas consumption trends can be compared is selected. I find natural gas consumption in BC decreased after the tax, but this decrease does not deviate from the time series of the synthetic control group. Therefore, the decline does not stand out relative to the distribution of placebo estimates for other states/provinces. In addition, a series of regression analyses are conducted, including a differences-in-differences model and a tax salience model, as robustness tests. Consistent with the synthetic control method, no statistically significant reduction in the per capita residential natural gas consumption is discovered in BC.

*Keywords*: Synthetic control method, carbon tax, natural gas consumption

JEL Classifications: C1 Q41 Q58

### 3.1. Introduction

In the most recent 20 years, both federal and local governments in North America have established targets to reduce greenhouse gas (GHG) emissions. To achieve these targets, both voluntary constraints (i.e., energy efficiency programs, and demand side management) and mandatory constraints (i.e., cap and trade, command and control, and carbon tax) have been applied. With respect to mandatory constraints, a carbon tax creates broad incentives to encourage individuals at all levels of society to reduce their carbon footprint through conservation, substitution, and innovation. Although there is no nationwide carbon tax levied in North America, a few states/provinces and localities have introduced carbon prices either through taxes or tradable permits.[42]

Passed in 2008, British Columbia's (BC) carbon tax is the most comprehensive carbon policy in North America.[43] In February 2008, the BC Finance Minister revealed the government's intention to implement North America's first revenue-neutral carbon tax. Aiming to reduce GHG emissions to 33 percent below 2007 levels by 2020, the carbon tax works as a central component of BC's climate change strategy (Government of British Columbia 2008; Elgie and McClay, 2013). The carbon tax was launched on July 1, 2008 at an initial level of \$10/tonne carbon dioxide emission ($CO_2$e), with annual increases of \$5/tonne scheduled through to 2012, at which point the tax was \$30/tonne. The Finance Minister also announced a one-time Climate Action Dividend of \$100 to be paid to every resident of BC in 2008 before the introduction of the carbon tax in July (British Columbia Ministry of Finance, 2008). A

[42] Table A3.1 in the Appendix presents an overview of the carbon tax policy in North America.

[43] Quebec implemented its carbon levy in October 2007. It became the first province in Canada to implement a carbon tax. The carbon levy is C\$3.50 per metric ton of CO2. The level is readjusted every year based on the volume of sales. When the provincial government imposed the green fund tax in 2007, its primary purpose was directly targeted at producers, not consumers (Torys LLP., 2007). Gaz Métro began charging 17.54 cents/GJ more on the retail price of natural gas that it sells to its customers in early 2008. It means \$15 more per year for the typical Gaz Métro residential customer. (The Montreal Gazette, 2008).

prominent feature of the BC carbon tax is revenue- neutrality. All revenues from the tax are returned to taxpayers, two- thirds through cuts to individual income taxes, and one-third through corporate tax cuts. In addition, a low income tax credit was introduced to compensate for the regressive effects of the carbon tax due to a large relative effect on low income families (Harrison, 2012). Table 3.1 displays the BC carbon tax rates on natural gas, prices of natural gas in BC, and characteristics of revenue neutrality. In general, BC's carbon tax obtained support from most economists and many leaders of Canadian businesses, and they agree that the carbon tax is the most cost-effective way to tackle GHG emissions (Sustainable Prosperity 2011; Van Loon and Mayeda 2013).[44]

Table 3.1. *BC carbon tax rates and characteristics of the revenue- neutrality*

| Year | Carbon Tax ($/tonnes) | Carbon Tax on Natural Gas ($/GJ) | Natural Gas Price in BC ($/GJ) | Average Provincial Income Tax Rate on $100,000 |
|---|---|---|---|---|
| July 1, 2008 | 10 | 0.50 | 13.56 | 8.02% |
| July 1, 2009 | 15 | 0.75 | 13.20 | 7.89% |
| July 1, 2010 | 20 | 1.00 | 13.14 | 7.86% |
| July 1, 2011 | 25 | 1.25 | 12.53 | 7.83% |
| July 1, 2012 | 30 | 1.50 | 11.55 | 7.72% |

Note: The carbon tax on natural gas presented in column (3) is converted from $/tonnes to cents/GJ. Column (4) in Table 1 indicates how the average provincial income tax rate on $100,000 fells from 2008 to 2012 due to revenue recycling from the carbon tax.

Though BC has had a carbon tax for almost six years, there has been little research assessing the performance of the BC carbon tax on energy consumption and GHG emissions. Within the existing literature, Elgie and McClay (2013) present evidence suggesting that BC's per capita consumption of fuels, including propane, motor gasoline, diesel, heat oil, and petroleum coke, subject to the carbon tax fell 19 percent when compared to the rest of Canada. In addition, they observe a reduction of GHG emissions per capita. According to the BC government report, in 2010 the consumption of total natural gas in BC declined more than the

[44] The initial reaction to the carbon tax immediately after the budget announcement was generally supportive: 54% of British Columbians supported the policy (Environics, 2011). However, residents of northern and rural communities perceived that the carbon tax was unfair to them because of the colder climate in the north and fewer transportation choices. Northern municipalities passed a series of resolutions condemning the provincial carbon tax in the spring of 2008 (Peet and Harrison, 2012).

rest of Canada relative to 2007 levels, including all natural gas consumption (Government of British Columbia 2012).[45] Regarding gasoline consumption, using monthly (and annual) province-level motor-vehicle gasoline consumption data, Rivers and Schaufele (2013) find that a carbon tax of $0.05 per liter on gasoline caused a 12.5 percent reduction in per capita fuel use through the end of 2011.

Currently, there is no research concentrating on the impact of the BC carbon tax on residential natural gas consumption. The primary purpose of this chapter is to fill this gap. In this chapter, both synthetic control and regression analyses are used to assess the impact of BC's carbon tax on residential natural gas consumption. All the empirical models use aggregate data, consistent with the prior research on gasoline demand (Elgie and McClay 2013; Rivers and Schaufele 2013). Whereas the prior research has been conducted using Canadian provinces as controls, in this research I use Canadian provinces and northern/western U.S. states as controls. This increases the sample size and, in many cases, northern/western U.S. states are more comparable to BC in terms of climate and demographics than other Canadian provinces.

The synthetic control method developed by Abadie, Diamond, and Hainmueller (2010) (henceforth "ADH")—a general differences-in-differences (DD) method—is used as the primary estimation approach in this chapter. This new data driven process is used to select a group of provinces/states against which the natural gas consumption trends of BC can be compared. The synthetic control method has several advantages compared to standard DD regression methods. In a synthetic control estimation, the weights assigned to each control unit are not "ad hoc".[46] Rather, certain selection criteria are followed. Therefore, the synthetic control method

[45] Consumption by natural gas producers and natural gas used for electricity generation are excluded.

[46] Control units are members of complementary groups in comparative experiments. They are in a group that does not receive the new treatment being studied.

makes explicit: (1) the relative contribution of each control unit in reproducing the unit of interest and (2) the similarities between the unit of interest and the synthetic control, both in the pre-treatment and post-treatment periods.[47] Under the synthetic control estimation, each unit in the control group is assigned to a weight, so that the constructed synthetic control group can best reproduce the treated unit. The weights assigned to each control unit are non-negative and sum to one. If a control unit is assigned a positive weight, that control unit makes a contribution to construction of the synthetic group. If a control unit is assigned zero weight, this implies the unit plays no role in reproducing the treated unit. Therefore, the synthetic control method provides a safeguard against extrapolation. Further, as mentioned by ADH, the choice of a synthetic control is totally independent of access to post-treatment outcomes. Therefore, the synthetic control method allows researchers to make a decision on study design, which is independent of knowing how those decisions will influence the conclusions.

As a robustness check, two regression analyses are used in this chapter. First, I estimate a tax salience model where the price is decomposed into the carbon tax and the carbon tax-exclusive price. This allows me to separately identify the impact of the carbon tax from the impact of market price changes on natural gas consumption. Second, I use a standard DD approach to assess changes in natural gas consumption, where all Canadian provinces and northern/western U.S. states are used in the control group.

Using the synthetic control method, I find little evidence that suggests per capita residential natural gas consumption declined in BC relative to the group of control provinces/states due to the carbon tax. Results from both the tax salience regression and DD regression suggest that there is no significant decrease in natural gas consumption due to BC's carbon policy, which is consistent with the results from using the synthetic control method.

[47] Unit of interest refers to the group that does receive the new treatment, i.e. the treated group.

Overall, most of the aggregate analyses presented in this chapter show consistent results regarding the impact of the BC carbon tax on residential natural gas consumption. That is, the carbon policy as a whole has not had a statistically significant impact on per capita residential natural gas consumption.

The rest of this chapter proceeds as follows: Section 3.2 describes the data and summary statistics; Section 3.3 reports the estimation from the synthetic control method; Section 3.4 presents the results using regression analyses. Section 3.5 concludes.

### 3.2. Data and summary statistics

I use aggregate annual state/province-level panel data for the period 1990–2012 to assess the impact of the BC carbon tax on residential natural gas consumption. I analyze data from six Canadian provinces (British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, and Quebec[48]) plus twenty eight states in the northern and western United States (California, Colorado, Connecticut, Idaho, Illinois, Indiana, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Vermont, Washington, Wisconsin, and Wyoming).

As pointed out by Maddala, Trost, Li and Joutz (1997) and Alberini, Gans, and Velez-Lopez (2011), heating degree days (HDD), the price of natural gas, prices of substitutes (electricity and heating oil), and real per capita income play an important role in determining per capita residential natural gas consumption. In this chapter, other than the above listed predictors, I also include the percentage of the population aged 65 and over and the percentage of population aged 15 and less, since demographic variables are important factors determining natural gas

[48] Prince Edward Island (PEI), New Brunswick (NB), and Newfoundland/Labrador (NL) are excluded from the control groups since natural gas is not the major energy for home heating in these provinces.

consumption (Brounen, Kok and Quigley, 2012; Davis and Killian, 2011). It is reasonable to assume seniors use more natural gas for home heating, whereas young people use less.

As mentioned above, HDD is an important predictor to capture the impact of temperature on energy consumption. HDD is calculated based on the number of degrees Celsius that the mean temperature is below 18 ℃. If the temperature is greater than or equal to 18 ℃, then the HDD will be zero for that day. Values below the base of 18 ℃ are used to estimate the heating requirements of buildings. Annual HDD for are calculated as follows:

$$HDD_k = \sum_{d=1\ldots365} 18 - T_{kd} \qquad if\ T_{kd} < 18 \tag{20}$$

where $HDD_k$ is annual HDD in location $k$; and $T_{kd}$ is the average outdoor temperature in location $k$ in day $d$.

Canadian provincial residential natural gas consumption data is obtained from CANSIM 129-0003.[49] Natural gas and heating oil prices for Canadian provinces are obtained from Statistics Canada CANSIM 129-0003 and 326-0009, respectively. Residential electricity prices in Canada are obtained from Quebec Hydro's comparison of electricity prices in major North American cities from 2006 to 2012 and from CANSIM 326-0003.[50] Provincial GDP estimates are obtained from CANSIM 384-0038. The all-items CPI for Canada is from CANSIM 326-0020. The heating degree days (HDD) data are obtained from Environment Canada (Environment Canada, 2014).

US state-level residential natural gas consumption data is obtained from the US Energy Information Administration (EIA, 2014a). Residential average retail prices of natural gas, electricity, and heating oil in the US are available from the EIA (EIA, 2014b, 2014c and

[49] In both Canada and US, aggregate natural gas consumption is divided by population to yield per-capita residential natural gas consumption.
[50] Quebec Hydro simply provides the comparison of electricity prices from 2006-2012. The electricity price before 2005 can be recovered by using CANSIM 3260003 -the electricity price index.

2014d).[51] State-level HDD data is obtained from the National Climatic Data Centre (National Climate Data Center, 2014). State-level per capita income is obtained from the U.S. Department of Commerce, Bureau of Economic Analysis (Bureau of Economic Analysis, 2013). The annual all-items CPI is obtained from the US Bureau of Labor Statistics (Bureau of Labor Statistics, 2014). To evaluate under the same measurement scale, all prices and income figures are converted into 2002 Canadian dollars.

Table 3.2 presents detailed summary statistics for the predictors used in this chapter. From 1990 to 2012, the annual average per capita natural gas consumption is 574.884 cubic meters. Figure 3.1 displays trends in residential per capita natural gas consumption in BC versus the remaining provinces and northern/western U.S. states for the period 1990 to 2012. Figure 3.1 reveals that per capita natural gas consumption in BC is lower than in the rest of the selected states/provinces over the 1990 to 2012 period.

Table 3.2. *Summary Statistics*

| Variable | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|
| Per capita natural gas consumption (cubic meter) | 574.884 | 275.878 | 14.897 | 1548.578 |
| Price of residential natural gas (cents/cubic meter) | 38.319 | 10.623 | 15.952 | 71.114 |
| Price of residential electricity (cents/kWh) | 11.627 | 3.895 | 5.555 | 22.791 |
| Price of residential heating oil (cents/liter) | 55.285 | 15.020 | 30.662 | 107.169 |
| Log real income per capita | 10.546 | 0.198 | 10.096 | 11.184 |
| Population aged 65 and over | 0.131 | 0.014 | 0.088 | 0.170 |
| Population aged 15 and less | 0.221 | 0.021 | 0.144 | 0.278 |
| GDP growth rate (%) | 4.828 | 3.461 | -16.402 | 29.552 |
| HDD (1,000's) | 3.834 | 0.936 | 1.453 | 6.660 |
| $HDD^2$ (100,000's) | 15.6 | 7.428 | 2.112 | 44.4 |

Note: Tax-exclusive Prices and per capita income are inflation-adjusted measured in 2002 Canadian dollars.

[51] Some states do not have price information for heating oil. For these states, I use the national average price to replace it.

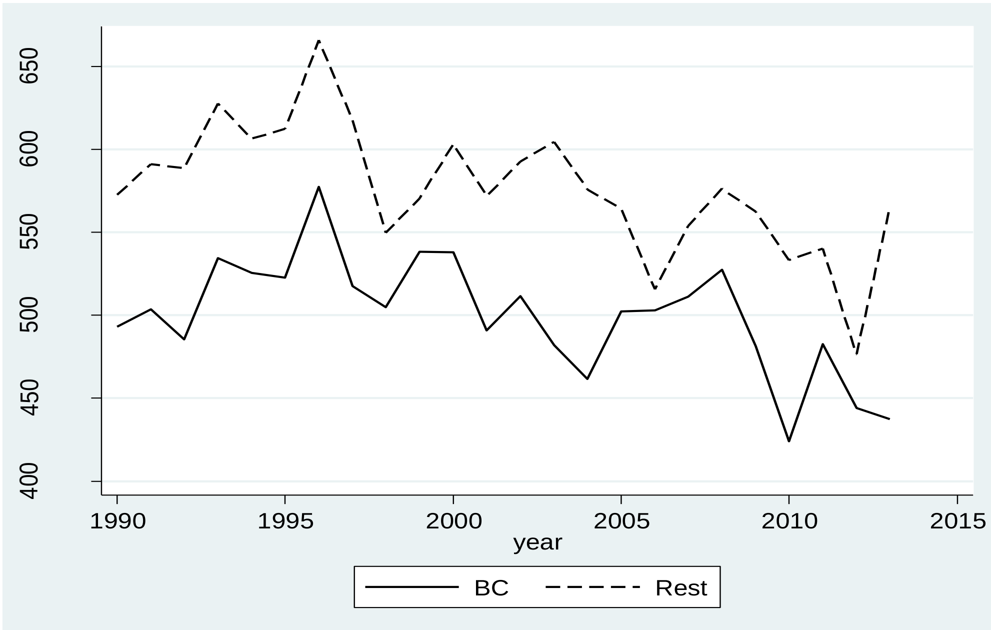



Figure 3.1. Trends in residential per capita natural gas consumption: BC versus the remaining Canadian provinces and northern/western U.S. states

Figure 3.2 displays trends in residential average per capita natural gas consumption in Canada versus the northern/western U.S. states from 1990 to 2012. Canadian per capita residential natural gas consumption has exceeded per capita consumption in northern/western US states over the most recent 23 years. This gap is likely largely driven by climatic differences between Canada and the US.

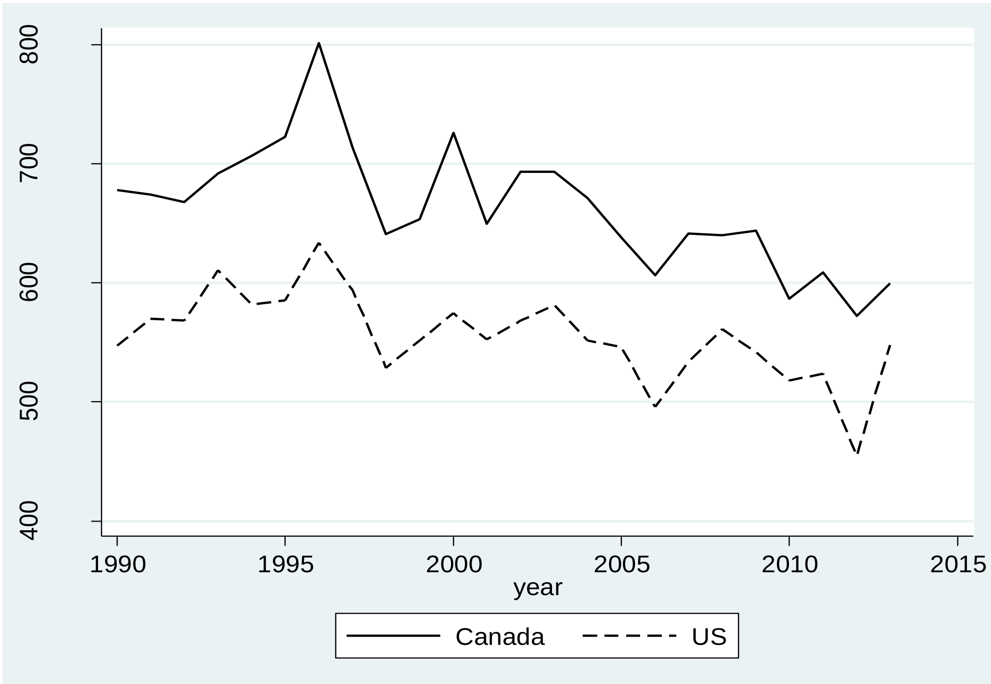



Figure 3.2. Trends in residential average per capita natural gas consumption: Canadian provinces versus the northern/western U.S. states

Regarding the rest predictors, among all the 34 states/provinces over the 1990 to 2012 period, the average annual price of residential natural gas is 38.319 cents/cubic meter, the annual average price of residential electricity is 11.627 cents/cubic meter, and the average price of residential heating oil is 55.285 cents/liter. The average log real income per capita is 10.546. The average percentage of population aged 65 and over is 13.1%, and the average percentage of population aged 15 and less is 22.1%. The mean percentage of the GDP growth rate is 4.828% and the average HDD days are 3,824.

## 3.3. Synthetic control method

### *3.3.1 Methodology*

In this section, a synthetic control method developed by ADH is applied. Suppose there is one treatment region, and the remaining $J$ regions serve as potential controls. Let the index $i = (1, \ldots, J+1)$ denote all provinces/states, where $i = 1$ corresponds to the treatment region (BC in this case) and $i = (2, \ldots, J+1)$ corresponds to each of the $J$ potential control provinces/states. Let $Y_{it}^{N}$ be the per capita residential natural gas consumption that would be observed in states/provinces *i* at time *t* without intervention, for units $i = 1, \ldots, J+1$, and time periods $t = 1, \ldots, T_0$. Let $T_0$ be the number of pre-intervention periods with $1 \leq T_0 \leq T$. Let $Y_{it}^{I}$ be the per capita residential natural gas consumption that would be observed in states/provinces *i* at time *t* without intervention, for units $i = 1, \ldots, J+1$, and time periods $t = T_0, \ldots, T$. Let $T - T_0$ be the number of the post-intervention periods.

Let $\alpha_{it} = Y_{it}^{I} - Y_{it}^{N}$ be the effect of the intervention for states/provinces *i* at time *t*.The objective is to estimate $\alpha_{1T_0+1}, \ldots, \alpha_{1T}$. ADH identify $Y_{it}^{N}$ by a factor model:

$$Y_{it}^{N} = \delta_t + \theta_t \boldsymbol{Z}_i + \lambda_t \mu_i + \varepsilon_{it}$$

where $\delta_t$ is an unknown common factor constant across states/provinces. $\boldsymbol{Z}_i$ is a vector of relevant observed, pre-treatment covariates that can be time invariant. In this chapter, $\boldsymbol{Z}_i$ is a vector including real prices of natural gas and its substitutes (electricity and heating oil), real per capita income, percentage of population aged over 65, and heating degree days (HDD). $\theta_t$ is a vector of unknown parameters, $\mu_i$ is a province/state-specific unobservable, $\lambda_t$ is an unknown common factor, and $\varepsilon_{it}$ captures random shocks with mean zero.

Define $\boldsymbol{W} = \left(w_2, \ldots, w_{J+1}\right)'$ as a $(J \times 1)$ vector of weights such that $w_i \geq 0$ and $w_2 + \cdots + w_{J+1} = 1$. Each possible choice of $W$ corresponds to a particular weighted average of control provinces/states. Let the $(T_0 \times 1)$ vector $\boldsymbol{K} = \left(k_1, \ldots, k_{T_0}\right)'$ define a linear combination of pre-intervention outcomes: $\bar{Y}_j^{\boldsymbol{K}} = \sum_{s=1}^{T_0} k_s Y_{js}$.

Consider $\boldsymbol{M}$ of such linear combinations defined by the vectors $K_1, \ldots, K_M$. Define $X_1 = \left(Z_1', \bar{Y}_1^{K_1}, \ldots, \bar{Y}_1^{K_M}\right)'$ as a $k \times 1$ vector of pre-treatment characteristics for the treated provinces/states. $X_0$ is a $(k \times J)$ matrix containing the same pre-treatment characteristics of the untreated provinces/states. That is, the $j$th column of $X_0$ is $\left(Z_j', \bar{Y}_j^{K_1}, \ldots, \bar{Y}_j^{K_M}\right)'$. In this chapter, variables included in $X_0$ and $X_1$ are the real prices of natural gas, electricity, and heating oil, real per capita income, percentage of population aged 65 and over, percentage of population aged 15 and under, and average per capita consumption of natural gas.

The vector $\boldsymbol{W}^*$ is then selected by solving the constrained quadratic minimization problem:

$$\boldsymbol{W}^* = \arg\min_{\boldsymbol{W}} (X_0 - X_1\boldsymbol{W})' V (X_0 - X_1\boldsymbol{W})$$

subject to the constraints $w_i \geq 0$ and $w_2 + \cdots + w_{J+1} = 1$, where $V$ is a $(k \times k)$ symmetric and positive semi-definite matrix. The product $X_1\boldsymbol{W}$ provides a weighted average of the pre-treatment vectors for all states/provinces omitting BC, with the difference between BC and this average given by $X_0 - X_1\boldsymbol{W}$. The value of $\boldsymbol{W}$ is chosen to yield a synthetic comparison group that best reproduces the pre-treatment BC.

### *3.3.2 Estimation results*

Trends in residential per capita natural gas consumption in BC versus the other provinces and northern/western U.S. states in the sample are displayed in Figure 3.1 for 1990 to

2012. Figure 3.1 suggests that these provinces/states may not provide a suitable comparison group for BC to study the effect of the carbon tax on per capita residential natural gas consumption. During the pre-treatment period (from 1990-2007), the time series of BC and the other states/provinces residential natural gas consumption differs notably. Therefore, using the rest of the states/provinces as a comparison group is not a good choice.

The synthetic BC is constructed as a convex combination of states/provinces in the donor pool that most closely reproduce actual BC residential per capita natural gas consumption. The weights are generated not only based on pre-treatment similarity of per capita residential natural gas consumption, but also based on pre-treatment predictors such as the price of natural gas, the price of electricity, the price of heating oil, per capita income, the percentage of population aged 65 and over, percentage of population aged 15 and less, HDD, and HDD square. As described in the methodology section, the weights are generated from a data driven process—minimizing the difference in annual per capita residential natural gas consumption between actual BC and synthetic BC—with no personal judgement once the donor pool is selected. Table 3.3 displays the assigned weights use to construct the synthetic BC. The weights reported in Table 3.2 indicate that BC's pre-treatment per capita residential natural gas consumption is best reproduced by a combination of California, Illinois, Missouri, Oregon, and Wyoming. All other states/provinces in the donor pool are assigned zero weight.

Table 3.3. *The weights assigned to the donor pool (Benchmark Model)*

| States/provinces | Weight |
|---|---|
| California | 0.024 |
| Illinois | 0.175 |
| Missouri | 0.106 |
| Oregon | 0.587 |
| Wyoming | 0.118 |

One concern with this analysis is the possibility that the control states/provinces adopted policies that reduced natural gas consumption at the same way as BC imposed the carbon tax. If this is the case, then the estimated impact of the carbon tax is likely to be attenuated. This is likely not an issue in this control sample. In California the Bay Area Air Quality Management District (BAAQMD) passed a carbon tax of 4.4 cents/ton of $CO_2$. However, keeping California in the donor pool will not bias the result. First, the carbon tax in the BAAQMD is applied directly to businesses, rather than on consumers. When utility companies pass the carbon fees through to natural gas consumers, the price of natural gas controls this impact. Second, and most important, the amount of the carbon fee in BAAQMD is relatively small when compared to the BC carbon tax and only applies to one region of California. Therefore, it is unlikely that this tax has had a substantial impact on aggregate residential energy consumption in California.

Table 3.4 reports the comparison of the pre-treatment characteristics of BC with the synthetic BC, as well as with the average of the 33 potential control states/provinces. We see that the average of the states/provinces in the pre-treatment period in 1990-2007 does not seem to provide a suitable control group for BC. In particular, prior to the BC carbon tax the average log real income per capita, real price of natural gas, the real price of electricity, HDD, and HDD square are higher in the 33 control states/provinces than in BC. Moreover, prior to the BC carbon tax average residential per capita natural gas consumption is substantially higher in the 33 control states/provinces than in BC. In contrast, the synthetic BC more closely reproduces the average per capita consumption and most of the predictors used to describe natural gas consumption in BC prior to the carbon tax.

Table 3.4. *Per capita natural gas consumption predictor means*

| | BC | | Average of 33 control |
|---|---|---|---|
| Variables | Real | Synthetic | states/provinces |
| Ln (Real income per capita) | 10.56 | 10.58 | 10.65 |
| Percentage of population aged 65 and over | 13.88 | 12.61 | 12.89 |
| Percentage of population aged 15 and less | 17.75 | 21.08 | 21.21 |
| Real price of natural gas | 45.29 | 45.83 | 44.34 |
| Real price of electricity | 6.62 | 8.73 | 11.52 |
| Real price of heating oil | 76.25 | 62.50 | 57.42 |
| HDD | 3144.63 | 3163.29 | 3779.91 |
| $HDD^2$ | 1.00e+07 | 1.05e+07 | 1.51E+07 |
| Natural gas sales per capita (1995-1999) | 532.18 | 529.96 | 603.17 |
| Natural gas sales per capita (2000) | 537.88 | 537.35 | 603.16 |
| Natural gas sales per capita (2003) | 481.91 | 515.93 | 604.56 |
| Natural gas sales per capita (2006) | 502.94 | 479.67 | 540.88 |
| Natural gas sales per capita (2007) | 511.12 | 501.42 | 553.99 |

Note: All variables except lagged natural gas sales are averaged for the 2003 - 2007 period. All the prices and income per capita are measured by Canadian dollars, and are adjusted by CPI in 2002 dollars. Residential natural gas prices are measured in cents/cubic meters, electricity prices are measured in cents/kWh, and heating oil prices are measured in cents/liter.

Figure 3.3 displays per capita residential natural gas sales for BC and its synthetic counterpart during the period 1990-2012. Notice that, in contrast to per capita consumption in other states/provinces (shown in Figure 3.1), per capita consumption in the synthetic BC more closely tracks the real BC in the pre-carbon tax period.

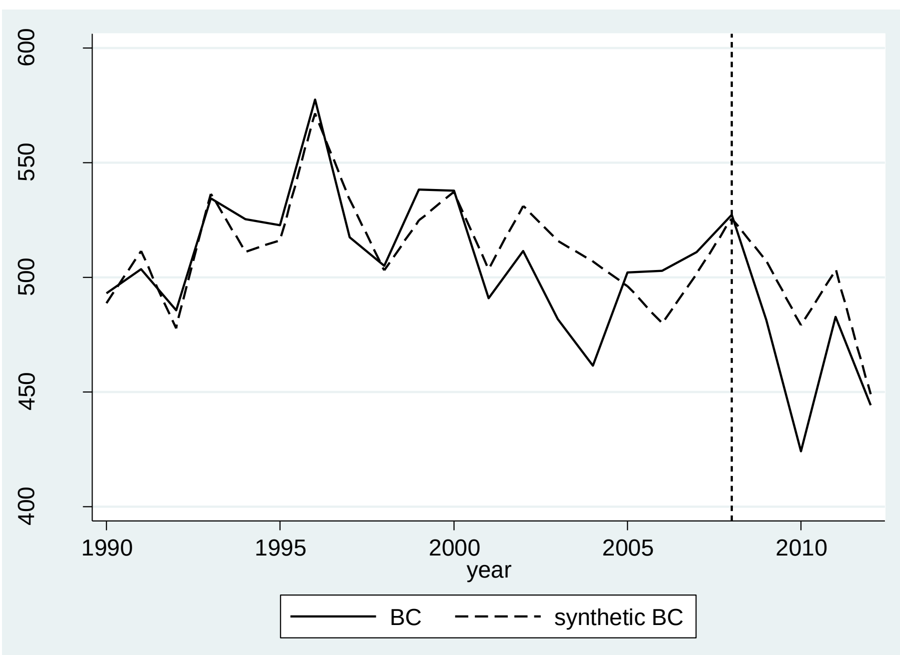



Figure 3.3. Trends in per capita residential natural gas sales: BC vs. synthetic BC measured in cubic meters

The gap between real BC and synthetic BC per capita residential natural gas consumption is calculated by $Y_{real} - Y_{synthetic}$. The upper panel of Table 3.5 displays the mean per capita natural gas consumption for BC, synthetic BC, and the difference between the two in the pre-treatment period from 1990 to 2007. The smaller the gap between actual BC and synthetic BC, the better the synthetic control tracks the real natural gas consumption in BC. In a perfect world, the pre-treatment gap would be equal to zero every year before 2008, which would imply that synthetic BC is a perfect fit for actual BC in terms of per capita natural gas consumption during the sample period from 1990 to 2007.

Table 3.5. *Real, synthetic and gaps of residential natural gas consumption in BC (Benchmark)*

| Year | Real BC ($Y_{real}$) | Synthetic BC ($Y_{synthetic}$) | Gap $(Y_{real} - Y_{synthetic})$ |
|---|---|---|---|
| | Pre-treatment: from 1990-2007 | | |
| 1990 | 493.02 | 480.92 | 12.10 |
| 1991 | 503.52 | 514.59 | -11.07 |
| 1992 | 485.59 | 476.98 | 8.61 |
| 1993 | 534.58 | 539.46 | -4.87 |
| 1994 | 525.49 | 504.67 | 20.82 |
| 1995 | 522.72 | 513.86 | 8.86 |
| 1996 | 577.54 | 557.55 | 19.99 |
| 1997 | 517.45 | 531.97 | -14.52 |
| 1998 | 504.92 | 489.09 | 15.83 |
| 1999 | 538.30 | 510.36 | 27.93 |
| 2000 | 537.88 | 521.21 | 16.66 |
| 2001 | 490.94 | 508.98 | -18.04 |
| 2002 | 511.42 | 516.09 | -4.67 |
| 2003 | 481.91 | 506.04 | -24.14 |
| 2004 | 461.45 | 491.18 | -29.73 |
| 2005 | 502.27 | 488.93 | 13.34 |
| 2006 | 502.94 | 466.67 | 36.27 |
| 2007 | 511.12 | 497.42 | 13.70 |
| Average (1990-2007) | 511.28 | 513.77 | -2.49 |
| | Post-treatment: from 2008-2012 | | |
| 2008 | 527.31 | 530.68 | -3.38 |
| 2009 | 481.30 | 501.74 | -20.45 |
| 2010 | 423.98 | 477.26 | -53.28 |
| 2011 | 482.68 | 493.29 | -10.60 |
| 2012 | 444.09 | 446.48 | -2.39 |
| Average (2008-2012) | 471.87 | 492.90 | -21.02 |

Note: Real, synthetic and gaps of residential natural gas consumption are measured in cubic meters.

In practice, with limited states/provinces in the donor pool, it is very difficult to find a perfect fit. Further, residential energy consumption typically fluctuates year to year and across provinces/states more than other goods and services. This contributes to difficulty in finding a perfect match. In this chapter, following ADH, the pre-treatment mean squared prediction error (MSPE) is used as the selection criterion to find the model specification that provides the best fit and minimizes the pre-treatment gap. The selection criterion is that given the sample, the smaller the MSPE, the better the job that the synthetic control group does in reproducing the real BC.

In the baseline specification, the MSPE is 17.26 which is low compared to other specifications. The estimates show that the average pre-treatment gap is 2.49 cubic meters and the maximum difference of magnitude is 36.27 cubic meters in 2006. The average percentage gap prior to the carbon tax is 0.48%.

The lower panel of Table 3.5 reports the outcomes for the post-treatment sample period from 2008 to 2012. The larger the gap, the greater the impact of the carbon tax. Per capita natural gas consumption in BC falls relative to the synthetic control group from 2008 to 2012. The average gap is -21.02 cubic meters, which represents an average difference of 4.45%. However, this change is non-monotonic, and it ranges from a difference of -53.28 to a difference of -2.39 cubic meters. The difference is never greater than zero in the post-treatment period, indicating that per capita BC natural gas consumption is always lower than per capita consumption in synthetic BC after the carbon tax is imposed.

### 3.3.3 *Placebo tests*

In this section I conduct placebo tests to evaluate the statistical significance of the synthetic control estimates. The purpose of running a placebo test is to assess the extent to which the results are driven by chance as opposed to the carbon tax policy itself. Following ADH, a placebo test is implemented by applying the synthetic control method to states/provinces that did not implement a carbon tax during the sample period of the study from 1990 to 2012. If the placebo studies create gaps of similar magnitude to the gap estimated for BC in the post-treatment period, then the interpretation is that the synthetic control analysis does not provide evidence of a statistically significant negative effect of the carbon tax on residential natural gas consumption. On the other hand, if the placebo studies show that the gap estimated for BC is large relative to the gaps for the states/provinces that did not impose a carbon tax, then we can draw the conclusion that the analysis does provide evidence of a statistically significant negative effect of the carbon tax on per capita residential natural gas consumption.

Figure 3.4 displays the placebo tests conducted by iteratively applying the synthetic control method to every other state/province in the donor pool, where BC is shifted to the donor pool. I then compute the estimated effect associated with each placebo test. The placebo test provides us with a distribution of estimated gaps for the states/provinces where no carbon tax took place.

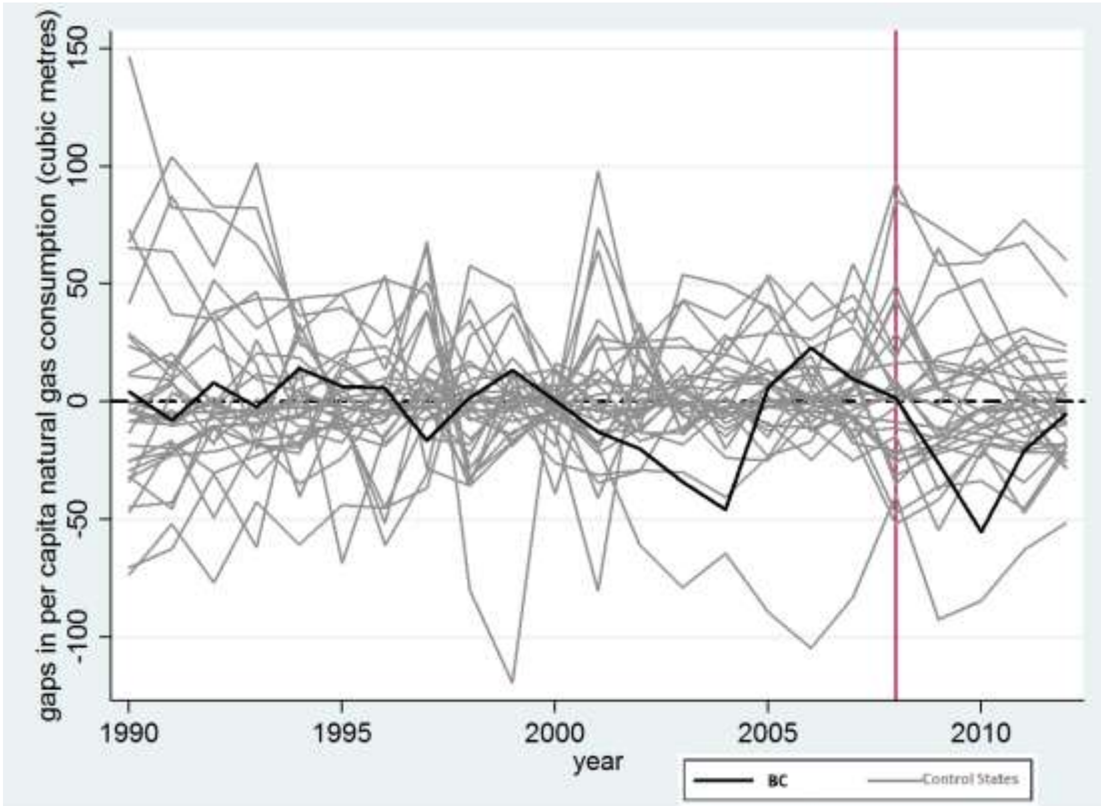


Figure 3.4. Residential per capita natural gas consumption gaps in BC and placebo gaps in control states/provinces

The super-imposed black line denotes the gap estimated for BC. The gray lines represent the gaps associated with each of the 31 runs of the placebo tests. That is, the gray lines show the difference in per capita natural gas consumption between each state/province in the donor pool and its respective synthetic version. Not all placebo effects are comparable to the case of BC. Among all the states/provinces in the donor pool, Alberta is the region with the highest per capita natural gas consumption for every year prior to the carbon tax. Therefore, there is no combination of states/provinces in our sample that can reproduce the time series of residential per capita natural gas consumption in Alberta prior to 2007. A similar problem arises in Maine with the minimum per capita consumption of natural gas every year prior to the carbon tax. In the placebo tests, Alberta and Maine are discarded. In Appendix Figure A3.1 and Figure A3.2, the trends for Alberta (Maine) and synthetic Alberta (Maine) natural gas consumption are reported.

Following Bohn, Lofstrom and Raphael (2014), the "placebo" DD estimate for all the states/provinces, including BC, is expressed as

$$DD_i = \left(Y_{post}^{i} - Y_{post}^{synth,i}\right) - \left(Y_{pre}^{i} - Y_{pre}^{synth,i}\right) \quad (21)$$

where *i* denotes the state/province receiving the placebo. Define $Y_{pre}^{i}$ as the average value of the per capita residential natural gas consumption for state/province *i* during the pre-treatment period. The corresponding average for the post-treatment period is defined as $Y_{post}^{i}$. Define the similar averages $Y_{pre}^{synth,i}$ and $Y_{post}^{synth,i}$ for the synthetic control group. If the cumulative density function (CDF) of the complete set of DD estimates is given by $F(.)$, the *p*-value from a one-tailed test of the hypothesis that $DD_i < 0$ is given by $F(DD_i)$. In the Appendix Table A3.4, I present the estimates of the $DD_i$ estimator laid out in equation (21) for all the states/provinces.

Table 3.6 presents estimates of several variants of the DD estimator for BC using the synthetic control. The first two columns present the average gaps between actual and synthetic BC residential natural gas consumption for both the pre-treatment and post-treatment periods. The remaining columns present the average DD estimates of the carbon tax, the rank of the estimate for BC relative to the distribution of all 32 estimates (one for BC and 31 placebo estimates), and the *p*-value from a one-tailed test of the likelihood of observing an estimated treatment effect less than or equal to the estimated treatment effect for BC. The average DD estimate for BC is -18.533 cubic meters. Within the distribution of the placebo estimates, BC has the 7$^{th}$ lowest treatment effect (most negative) among the 32. The *p*-value from this test is bounded from below by 0.219. This implies that although the average impact of the BC carbon tax is negative, it is not statistically significant.

Table 3.6. *Significance test of differences-in-differences analysis for BC (benchmark)*

| Sample period | Gap pre-treatment (cubic meters) | Gap post-treatment (cubic meters) | $DD_{BC}$ (cubic meters) | Rank (lowest to highest) | $P$-value from one tailed test $P(DD_i < DDBC$ |
|---|---|---|---|---|---|
| 1990-2012 | -2.489 | -21.023 | -18.533 | 7/32 | 0.219 |

Figure 3.5 displays the cumulative DD estimates for all 32 states/provinces.[52] As we noticed, the DD estimate for BC is -18.533 cubic metres with a corresponding probability of 0.219, which is not statistically significant at conventional significance levels.

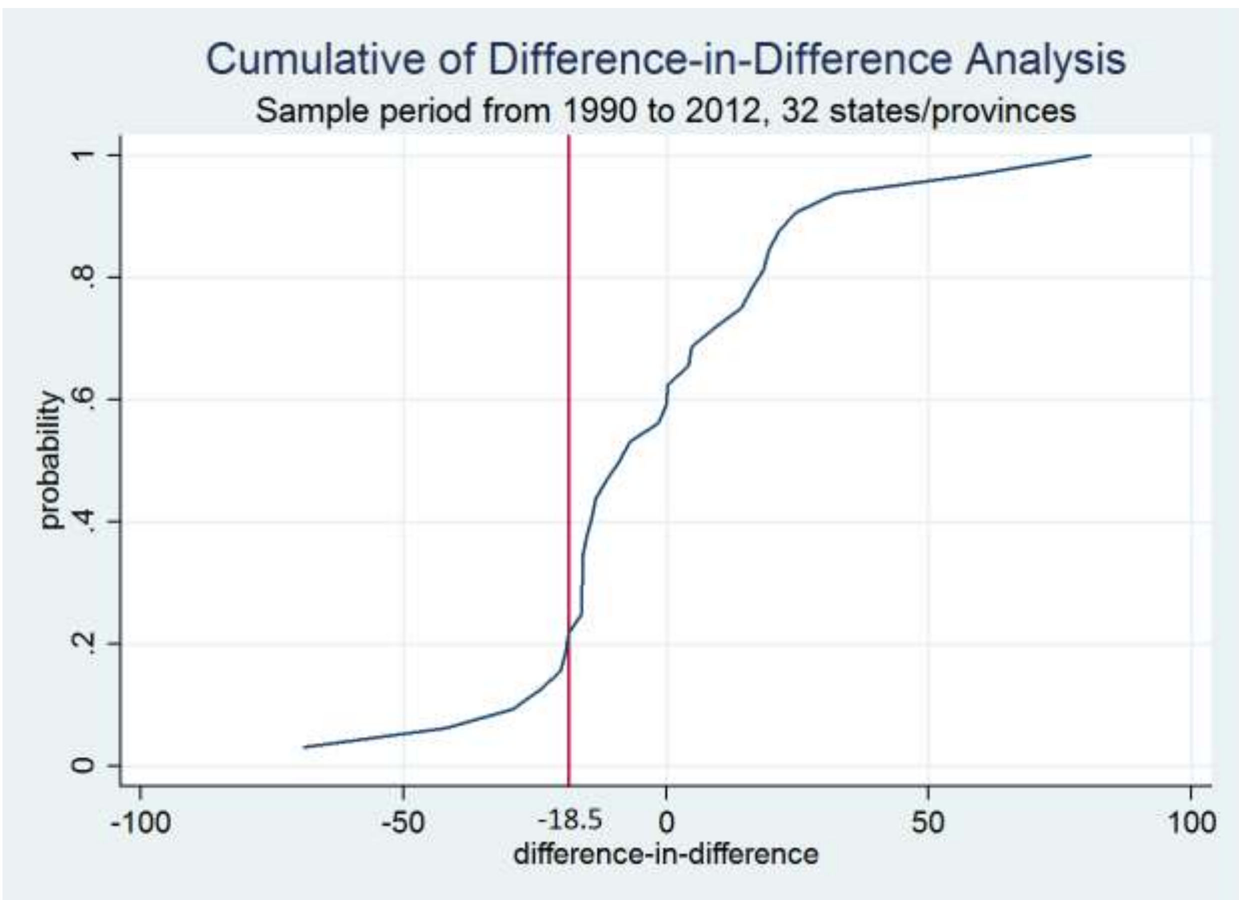



Figure 3.5. Cumulative of Difference-in-Difference Analysis

[52] 32 rounds of placebo tests include 31 rounds for control units and 1 for treatment unit.

### 3.3.4. *Robustness Tests*

To probe the robustness of the estimation, a series of additional synthetic control estimates are conducted. I first test to what extent the reported result is sensitive to dropping some predictors. Second, a limited sample period is chosen from 2000-2012 to test whether the result is sensitive to the sample period. Third, states/provinces which do not use hydroelectricity as a major source of electricity generation are dropped from the sample. Table 3.6 presents the average DD estimates and the related significance tests for these alternative specifications.

Table 3.7. *Average differences-in-differences estimates and significance tests (robustness check)*

| | Sample Period | Gap pre-treatment (cubic meters) | Gap post-treatment (cubic meters) | $DD_{BC}$ (cubic meters) | Rank (Lowest to highest) | $P$-value from one tailed test, $\Pr(DD_i < DDBC$ |
|---|---|---|---|---|---|---|
| Baseline | 1990-2012 | -2.489 | -21.023 | -18.533 | 7/32 | 0.219 |
| (2) | 1990-2012 | -3.390 | -17.870 | -14.480 | 12/32 | 0.375 |
| (3) | 2000-2012 | 1.575 | -27.475 | -29.050 | 2/32 | 0.063 |
| (4) | 1990-2012 | -2.451 | -23.044 | -20.593 | 3/13 | 0.230 |

As discussed in the previous section, the average per capita natural gas consumption, the price of natural gas, the price of electricity, the price of heating oil, real income per capita, percentage of the population aged 65 and over, percent of the population aged 15 and less, HDD and HDD square are used as predictors reported in the baseline specification in row (1) of Table 3. 7.

In the first robustness test, I drop two predictors: the price of electricity and the price of heating oil.[53] Table 3.8 reports the weights assigned to the donor pool in the construction of synthetic BC when these two predictors are dropped. Among the states/provinces with positive weights, Oregon obtains most of the weight (0.553), followed by Missouri (0.224), Illinois

[53] Electricity and heating oil are subsitutes of natural gas for home heating. The heating equipment is durable good and the average replacing age is around 17 years (Davis, 2011). When considering the short/medidum-run of the carbon tax, the prices of electricity and heating oil may not affect the household natural gas consumption.

(0.108), Colorado (0.088), and Montana (0.028). Boulder, Colorado implemented the United States' first carbon tax on emissions on April 1, 2007. Since the Boulder Colorado carbon tax is on electricity consumption, keeping Colorado in the donor pool is not likely to introduce substantial bias into the estimation.[54]

Table 3.8. *Weights assigned to the donor pool (dropping two predictors)*

| States/provinces | Weights |
|---|---|
| Colorado | 0.088 |
| Illinois | 0.108 |
| Missouri | 0.224 |
| Montana | 0.028 |
| Oregon | 0.553 |

Row (2) in Table 3.7 reports the average DD estimates and the related significance test when two predictors are dropped. The DD estimate is -14.480. Within the distribution of the placebo estimates, it ranks 12th out of 32 and the *p*-value from a one-tailed test is 0.375. Similar to our baseline model, we find the average impact of the carbon tax is statistically insignificant on per capita residential natural gas consumption.

In the second robustness test, the pre-treatment sample period is limited to 2000 - 2007. This specification uses the same predictors and donor states as the baseline model. Since 2000, the development in technology of horizontal drilling for shale gas increased shale gas production in the US. It is estimated that shale gas production increased from 1% to 20% between 2000 and 2010, and it is believed that the rise of shale gas production has caused downward pressure on gas prices worldwide (Stevens, 2012; Aruga, 2013). Therefore, in this chapter, to account for possible structural changes in the gas market, a shorter sample period is used from 2000 to 2012. Once the sample period is changed, the optimal weights assigned to the donor states/provinces also change. Table 3.9 reports the weights assigned to the donor pool in construction of the

[54] It is possible the carbon tax on electricity consumption will make some households install natural gas heating equipment, especially for new buildings. Few households will consider the small carbon tax a reason to replace natural gas heating equipment. Therefore , the carbon tax on electricity in Boulder should not greatly affect consumption of natural gas.

synthetic BC using sample data from 2000-2012. Weights reported in Table 3.9 indicate that Oregon, Idaho, Colorado, and Saskatchewan best reproduce synthetic BC in the shorter pre-treatment period.

Table 3.9. *Weights Assigned to the donor pool (sample period 2000-2012)*

| States/provinces | Weights |
|---|---|
| Oregon | 0.427 |
| Idaho | 0.312 |
| Colorado | 0.141 |
| Saskatchewan | 0.121 |

Row (3) in Table 3.7 reports the significance test of the DD analysis for BC using a shorter sample period from 2000 to 2012. The average DD estimate for BC is -29.05. It ranks the second lowest out of 32 groups and the *p*-value for the one-tailed test improves to 0.063. This result provides weak evidence that the carbon tax did have a statistically significant impact on per capita residential natural gas consumption.

In the third robustness test, states/provinces that do not use hydroelectricity as a major electricity generation source are dropped from the sample. In BC, 86.3% of the electricity is generated from hydroelectricity (British Columbia Ministry of Energy and Mines, 2012). Electricity is an important substitute for natural gas for home heating. In order to be comparable to BC, states/provinces which generate less than 10% of their total electricity from hydroelectricity are dropped from the sample. This leaves 12 donor states/provinces. Table 3.10 reports the weights assigned to the donor pool when 21 states are removed from the sample. Oregon, Iowa, Colorado, Manitoba, and Montana are assigned positive weights to construct synthetic BC.

Table 3.10. *The weights assigned to the donor pool (12 states in the donor pool)*

| States/provinces | Weights |
|---|---|
| California | 0.205 |
| Idaho | 0.159 |
| Manitoba | 0.123 |
| New York | 0.512 |

Row (4) in Table 3.7 presents the results of significance test of the DD analysis for BC using 12 states/provinces in the donor pool. The average DD estimate for BC is -20.593. Among the distribution of placebo estimates, BC ranks the third lowest out of 13 and the *p*-value of the significance test is 0.230 implying the impact of the carbon tax is statistically insignificant.

## 3.4. Regression Estimates

### 3.4.1 *Tax Salience Model*

*A. Empirical Methodology*

To estimate the relative impact of carbon changes on per capita residential natural gas consumption, I begin by employing an empirical approach similar to Chetty, Looney, and Kroft (2009), Davis and Kilian (2010), Rivers and Schaufele (2012), and Li, Linn and Muehlegger (2014). I consider a regression in which the price is decomposed into a tax-exclusive component and the carbon tax.[55] For per capita residential natural gas consumption, I estimate the following linear regression:

$$\log(q_{it}) = \alpha_0 + \alpha_1 p_{1it} + \alpha_2 p_{2it} + \alpha_3 p_{3it} + \alpha_4 \tau_{it} + \mathbf{X}_{it}\theta + \gamma_t + \epsilon_{it} \qquad (22)$$

where $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ and θ are parameters to be estimated; $q_{1it}$ is per capita cubic meters of residential natural gas consumed in state/province *i* during year *t*; the tax-exclusive inflation adjusted prices of natural gas, electricity, and heating oil are $p_{1it}$, $p_{2it}$, and $p_{3it}$, respectively; the carbon tax is expressed as $\tau_{it}$; and the matrix $\mathbf{X}_{nt}$ represents relevant control variables that vary at the state/province-year level. The time fixed effects, $\gamma_t$, capture time- specific unobserved factors such as national policies or federal regulations influencing natural gas consumption. The error term is $\epsilon_{it}$. In this chapter, a fixed effects (FE) model is used in the estimation since it can better capture across-group heterogeneity, such as regional variation in energy efficiency programs and other policies or demographic structures that vary across provinces/states.

[55] Federal/ provincial sales taxes are not included in our analysis. Those taxes are applied generally on all goods and services.

I control for several variables expected to influence per capita natural gas consumption. These include province/state real per capita income, the percentage of the population aged 65 and over, the percentage of the population aged 15 or less, HDD, and HDD squared.

I assume that the tax-exclusive price and the carbon tax are exogenous sources of variation. As I discussed in the background section, the primary purpose of the BC carbon tax is to reduce carbon dioxide emissions. The tax rates are fixed and were announced in July 2008, so the tax rate is independent of natural gas consumption. In terms of natural gas prices, following Davis and Killian (2011), I assume that changes in residential natural gas prices are not driven by natural gas consumption used for residential heating.

There are two reasons why price endogeneity is not likely to be a problem in this chapter. First, the fixed effect model controls for unobserved heterogeneity across states/provinces. In addition, in the baseline model, I include the time fixed effects which control for unobserved changes in demand over time. Second, residential natural gas prices consist of three elements: the wholesale price of natural gas from producing areas, pipeline transportation costs, and local distribution and storage charges. Because of the large transportation cost, natural gas prices vary from west to east in Canada. For example, prices are generally higher in Quebec and New Brunswick than in Alberta and British Columbia where most of the gas is produced. Although transportation costs decrease over time, these savings are caused by regulatory reform and technological improvement rather than changes in residential demand (Leitzinger and Collette 2002). Further, there is an integrated wholesale market for natural gas.[56] Therefore, local demand changes tend not to result in large local price changes.

[56] In Canada, the wholesale market is in Alberta; in the US, the wholesale market is in Louisiana.

*B. Results*

Table 3.11 presents estimates from the fixed effects model for several alternative specifications. Column (1) in Table 3.11 is the baseline specification using annual data from 1990 to 2012 with 782 observations. I regress the log of household natural gas consumption on the price of natural gas, the price of electricity, the price of heating oil, the carbon tax, log real income per capita, percentage of population aged over 65, the percentage of the population aged less than 15, HDD, HDD square, and year fixed effects. All prices, carbon tax, and per capita income are adjusted by the CPI and are measured in 2002 Canadian dollars. I find there is no significant impact of the carbon tax on residential natural gas consumption. Further, I find that the price of natural gas, the price of electricity, the price of heating oil, real per capita income, and percentage of population aged 65 and over do not significantly affect per capita residential natural gas consumption. HDD and the percentage of the population aged less than 15 greatly influence natural gas consumption. The climate is among the most important determinants of natural gas consumption and, not surprisingly, I find that increases in HDD increase natural gas consumption. I find that provinces/states with a higher share of young people consume less natural gas. Specifically, a one percent increase in the share of the population aged 15 and less decreases natural gas consumption by 3.5%.

Table 3.11. *Effect of natural gas prices and carbon taxes on residential natural gas consumption*

| | (1)-baseline | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Price of residential natural gas $(\alpha_1)$ | -0.002 | -0.001 | 0.001 | -0.003* | 0.004 |
| | (0.002) | (0.002) | (0.001) | (0.002) | (0.004) |
| Price of residential electricity $(\alpha_2)$ | 0.006 | | 0.008 | -0.008 | 0.012 |
| | (0.010) | | (0.007) | (0.006) | (0.017) |
| Price of residential heating oil $(\alpha_3)$ | -0.000 | | -0.003*** | -0.004** | -0.005** |
| | (0.002) | | (0.001) | (0.002) | (0.002) |
| Carbon tax $(\alpha_4)$ | -0.025 | -0.027 | -0.023 | -0.034*** | -0.038 |
| | (0.017) | (0.016) | (0.014) | (0.010) | (0.021) |
| Real log income per capita | -0.075 | -0.060 | -0.001 | 0.191*** | -0.243 |
| | (0.097) | (0.070) | (0.051) | (0.082) | (0.145) |
| Percent of population aged over 65 | 0.034 | 0.036 | 0.023 | 0.055* | -0.004 |
| | (0.029) | (0.026) | (0.025) | (0.032) | (0.044) |
| Percent of population aged less than 15 | -0.035*** | -0.036*** | -0.021** | -0.035 | -0.046 |
| | (0.012) | (0.012) | (0.008) | (0.023) | (0.028) |
| HDD (1,000s) | 0.304*** | 0.314*** | 0.324*** | 0.284*** | 0.006 |
| | (0.090) | (0.095) | (0.078) | (0.091) | (0.098) |
| $HDD^2$ (10,000,000s) | -0.013 | -0.013 | -0.014 | -0.013 | 0.000** |
| | (0.066) | (0.009) | (0.009) | (0.009) | (0.000) |
| Time fixed effects | Yes | Yes | No | Yes | Yes |
| No. of observations | 782 | 782 | 782 | 442 | 299 |
| Sample period | 1990-2012 | 1990-2012 | 1990-2012 | 2000-2012 | 1990-2012 |
| No. of states/provinces | 34 | 34 | 34 | 34 | 13 |
| $R^2$-within | 0.46 | 0.45 | 0.39 | 0.67 | 0.38 |
| $R^2$-between | 0.05 | 0.04 | 0.06 | 0.02 | 0.23 |
| $R^2$-overall | 0.03 | 0.02 | 0.04 | 0.01 | 0.18 |

Note:*, **, and *** denote significance at the 10%, 5% and 1%. Standard errors are in parentheses.

Columns (2)-(5) in Table 3.11 present the results for several alternative specifications. Column (2) reports the results of a model that drops the price of electricity and the price of heating oil. As in the baseline specification, under this specification I find that the carbon tax has no impact on natural gas consumption. Column (3) in Table 3.11 presents results for specifications where time fixed effects are not included in the model. I find no significant impact of the carbon tax on natural gas consumption.

Column (4) in Table 3.11 presents results using a shorter period of sample from 2000 to 2012 to account for the possibility that structural change has influenced the natural gas market and responses to prices and taxes. Under this specification, I find that the carbon tax has a statistically significant impact on natural gas consumption. The point estimate shows that a one cent/cubic meter increase in the carbon tax decreases natural gas consumption by 3%. This suggests that estimates of the impact of the carbon tax depend on the sample period considered. Weak evidence of this was presented in the previous section using the synthetic control approach.

Column (5) in Table 3.11 displays the results of using states/provinces with hydroelectricity as their major electricity generation. As in the baseline specification, I find the carbon tax does not have a significant impact on natural gas consumption. Overall, when the tax salient regression model is used for estimation, the majority of the specifications show that there is no significant impact of changes in the carbon tax on natural gas consumption. This conclusion is consistent with the results found using the synthetic control method.

### 3.4.2. *Standard DD analysis*

#### *A. Empirical Methodology*

Under the standard DD model, the following regression is estimated:

$$\log(q_{it}) = \beta_0 + \beta_1 p_{1it} + \beta_2 p_{2it} + \beta_3 p_{3it} + \beta_4 Year + \beta_5 BC + \beta_6 (BC * Year) + \mathbf{X}_{it}\theta + u_{it} \quad (23)$$

where $\beta_0$, $\beta_1$, $\beta_2$, $\beta_3$ , $\beta_4$, $\beta_5$ , $\beta_6$, and θ are parameters to be estimated; the dummy variable *Year* is a time indicator with $Year = 1$ if year is greater than or equal to 2008 and $Year = 0$ otherwise; the dummy variable *BC* is a state/province indicator with $BC = 1$ if the province is British Columbia, and $BC = 0$ for the rest of the states/provinces; $BC * Year$ is an interaction term; $\mathbf{X}_{it}$ is a set of control variables for province/state *i* and year *t*; and $u_n$ is the error term. In the standard DD method the coefficient of the interaction term, $\beta_6$, captures the treatment effect of BC's carbon policy. If $\beta_6$ is negative and statistically significant, this suggests that the effect of the carbon policy in BC is to reduce residential natural gas consumption.

#### *B. Results*

The standard DD approach yields results similar to those from the tax salience model reported in section 3.4.1. Table 3.12 presents the results of the standard DD estimates for several model specifications. All regressions are estimated by Ordinary Least Squares. Column (1) presents our baseline specification using the full 1990 to 2012 sample with 34 states/provinces included. The explanatory variables used in the baseline model include prices of natural gas, electricity, and heating oil, per capita log real income, percentage of population aged 65 and over, percentage of population aged 15 and under, year fixed effects, province fixed effects, and the DD interaction term. In the baseline model, I find the estimated coefficient of the treatment effect term ($\beta_6$) is insignificant, which implies that the BC carbon tax did not generate a significant decline in natural gas consumption during the study period. I also find the HDD and the price of heating oil do not play important roles in determining the natural gas consumption. The estimated coefficient of the price of natural gas is equal to -0.042. It implies a one cent/cubic meter increase of natural gas price will decrease residential natural gas consumption by 4.2%. I find increasing the price of electricity decreases natural gas consumption, which implies under the standard DD model that natural gas and electricity are complement energy sources for home heating. Further, when income per capita, the percentage of population aged 65 and over, and the percentage of population aged 15 and under increase residential natural gas consumption will also increase.

Column (2) in Table 3.12 reports the results of a specification with the price of electricity and the price of heating oil dropped. The specification in column (3) limits the sample from 2000 to 2012. Column (4) drops states/provinces that generate less than 10% of electricity from hydroelectric sources. Similar to the specification reported in column (1), the estimated coefficients of the interaction term $\beta_6$ are statistically insignificant across all of these specifications. This consistent finding suggests the carbon tax in BC has no impact on residential natural gas consumption.

Table 3.12. *Estimates of standard differences-in-differences model*

| | (1)-baseline | (2) | (3) | (4) |
|---|---|---|---|---|
| Price of residential natural gas $(\beta_1)$ | -0.042*** | -0.047*** | -0.043*** | -0.052*** |
| | (0.003) | (0.006) | (0.004) | (0.006) |
| Price of residential electricity $(\beta_2)$ | -0.055*** | | -0.038*** | -0.042*** |
| | (0.003) | | (0.017) | (0.021) |
| Price of residential heating oil $(\beta_3)$ | 0.010 | | 0.005* | 0.030*** |
| | (0.011) | | (0.003) | (0.004) |
| Year $(\beta_4)$ | -0.334*** | -0.086 | -0.298*** | -0.181 |
| | (0.077) | (0.067) | (0.083) | (0.144) |
| BC $(\beta_5)$ | 0.034 | -0.170* | 0.109 | 0.560*** |
| | (0.086) | (0.101) | (0.091) | (0.156) |
| BC*Year $(\beta_6)$ | 0.056 | 0.157 | 0.212 | -0.232 |
| | (0.127) | (0.130) | (0.123) | (0.256) |
| Real log income per capita | 2.209*** | 1.892*** | 2.084*** | 3.250*** |
| | (0.166) | (0.146) | (0.180) | (0.460) |
| Percent of population aged over 65 | 0.120*** | 0.077*** | 0.128*** | -0.015 |
| | (0.015) | (0.015) | (0.015) | (0.055) |
| Percent of population aged less than 15 | 0.118*** | 0.055*** | 0.128*** | 0.176*** |
| | (0.018) | (0.014) | (0.018) | (0.022) |
| HDD (1,000s) | -0.051 | 0.080 | 0.070 | 0.535** |
| | (0.132) | (0.169) | (0.180) | (0.240) |
| $HDD^2$ (10,000,000s) | -0.020 | -0.041* | -0.024 | -0.049 |
| | (0.018) | (0.022) | (0.024) | (0.031) |
| No. of observations | 782 | 782 | 442 | 299 |
| Sample period | 1990-2012 | 1990-2012 | 2000-2012 | 1990-2012 |
| No. of states/provinces | 34 | 34 | 34 | 13 |
| $R^2$ | 0.39 | 0.46 | 0.48 | 0.57 |

Note:*, **, and *** denote significance at the 10%, 5% and 1% levels. Standard errors are in parentheses.

### 3.5. Conclusion

Using panel data from 34 states/provinces 1990 to 2012, this study investigates the impact of BC's carbon tax on residential natural gas consumption using a synthetic control approach and other regression methods. I find that BC's carbon tax does not significantly decrease per capita residential natural gas consumption in BC**.** Although the synthetic control method shows that natural gas consumption in BC did decline, the magnitude of the decline is not statistically significant. In addition, most of the robustness tests demonstrate that there is little impact of the BC carbon tax on natural gas consumption. Moreover, the results from the regression analyses confirm the synthetic control method results. Neither the tax salience regression nor the standard DD regression shows a significant decrease in natural gas consumption after imposing the carbon tax. The possible explanation for that is the demand of residential natural gas consumption is very price/tax inelastic. Replacing heating equipments cost a lot compared to the carbon tax, therefore one may less likely observe an energy substitution across heating fuels. The less substitutibility to other energy in home heating implies an inelastic demand of natural gas in the short and medium run. In addition, factors such as climate and dwelling and household characteristics are more important determinants of natural gas consumption.

However, it is still too early to conclude that BC's carbon tax has no effect on residential natural gas consumption. Due to the limitation of the sample, only five years of post-policy data can be observed. To discover the long run impact of the BC carbon tax, more observations in the post-policy period are required. It is quite possible that there is a reaction lag of households responding to the carbon tax policy. The primary purpose of the BC carbon tax is to encourage people to adopt a greener lifestyle. However, because of consumption habits people's behaviour may need a longer time to adjust.

Further, this chapter gives us an overall impact of the BC carbon tax on natural gas consumption using aggregate data. It is not able to distinguish household reactions to the carbon tax, which may vary according to environmental ideology, household income, and social class. It is reasonable to assume that people with different environmental ideology, income or social class may have different attitudes toward the carbon tax. Therefore, their responses to the carbon tax policy may also vary.

**REFERENCES**

Abadie, A., A. Diamond, and J. Hainmueller. 2010. Synthetic Control Methods for Comparative Case Studies: Estimating the Effects of California's Tobacco Control Group. *Journal of the American Statistical Association* 105: 495–505.

Alberini, A., W. Gans, and D. Velez-Lopez. 2011. Residential consumption of gas and electricity in the U.S.: The role of prices and income. *Energy Economics* 33: 870-881.

Aruga, K. 2013. The U.S. Shale Gas revolution and Its Effect on International Gas Markets. http://mpra.ub.uni-muenchen.de/49545/

Allcott, H., and M. Greenstone. 2012. Is There an Energy Efficiency Gap? *Journal of Economic Perspectives* 26(1): 3-28.

Bureau of labor Statistics. 2014. All-item- CPI from 1913 to 2013. http://www.bls.gov/cpi/

Brounen, D., N. Kok, and J.M. Quigley. 2012. Residential Energy Use and Conservation: Economics and Demographics. *European Economic Review* 56: 931-945.

Bohn, S., M. Lofstrom, and S. Raphael. 2014. Did the 2007 Legal Arizona Workers Act Reduce the State's Unauthorized Immigrant Population? *The Review of Economics and Statistics.* 96(2):258-269.

British Columbia Ministry of Finance. Carbon Tax. 2014. http://www.fin.gov.bc.ca/tbs/tp/climate/carbon_tax.htm

British Columbia Ministry of Energy and Mines. 2012. Electric Generation and Supply. http://www.empr.gov.bc.ca/EPD/ELECTRICITY/SUPPLY/Pages/default.aspx

Carbon tax considered in green strategy. Kamloops Daily News. October 5, 2007. p. A3.

Cameron, A.C., and P. Trivedi. 2010. Microeconometrics Using Stata (Revised Edition). College Station, Texas: StataCorp LP.

California Legislative Information. SB-1156 California Carbon Tax Law of 2014. http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB1156

Chetty, R., A. Looney, and K. Kroft. 2009. Salience and Taxation: Theory and Evidence. *American Economic Review* 99(4): 1145-77.

Canada.com. 2008. Carbon tax bill in the mail. http://www.canada.com/montrealgazette/story.html?id=5a0e128d-c60a-4f31-a5b4-4dabd49c5bf2

Davis, L., and L. Kilian. 2011. The Allocative Cost of Price Ceilings in the U.S. Residential Market for Natural Gas. *Journal of Political Economy* 119(2): 212 - 241.

Elgie, S., and J. McClay. 2013. Policy Commentary: BC's Carbon Tax Shift is Working Well after Four Years. *Canadian Public Policy* 39(2): 1-10.

Energy Information Administration. 2014. Natural Gas Consumption by End User. http://www.eia.gov/dnav/ng/ng_cons_sum_a_EPG0_vrs_mmcf_a.htm

Energy Information Administration. 2014. Natural Gas Prices- Residential Prices. http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm

Energy Information Administration. 2014. U.S. Weekly No. 2 Heating Oil Residential Price (Dollars per Gallon). http://www.eia.gov/dnav/pet/pet_pri_wfr_a_EPD2F_PRS_dpgal_w.htm

Energy Information Administration. 2014. Table 5.6.A. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector.
http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a

Environment Canada. 2014. Monthly Climate Summary.
http://climate.weather.gc.ca/prods_servs/cdn_climate_summary_e.html

Environics Research Group. 2008. British Columbians Give a Nod of Approval to Their New Provincial Carbon Tax. 29 February.
http://researchenvironicsnet.sitepreview.ca/english/Environics%20%20BC%20Carbon%20Tax%20Press%20Release%20-%20February%2029-2008.pdf

Government of British Columbia. 2008. Carbon Tax Act. SBC 2008, ch. 40.

Government of British Columbia.. 2012. Making Progress on BC's Climate Action Plan. Victoria, BC: Ministry of Environment.

Harrison, K. 2012. A tale of two taxes: The fate of environmental tax reform in Canada. *Review of Policy Research* 29 (3): 1541-1338.

Leitzinger, J., and M. Collette. 2002. A Retrospective Look at Wholesale Gas: Industry Restructuring. *Journal of Regulatory Econ.* 21(1): 79–101.

Li, S., Linn, J., and E. J. Muehlegger. 2014. Gasoline Taxes and Consumer Behaviour. *American Economic Journal: Economic Policy,* 6(4):1-43, 2014.

Loughran, D.S., and J. Kulick. 2004. Demand-side management and energy efficiency in the United States. *The Energy Journal*. 5(1).

Maddala, G.S., R.P. Trost, H. Li, and F. Joutz. 1997. Estimation of short-run and long-run elasticities of energy demand from panel data using shrinkage estimators. Journal of Business & Economic Statistics. 15 (1): 90–100.

National Climate Data Center, NOAA Satellite and Information Service, U.S. Department of Commerce. 2014. http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp#

Natural Resources Canada. ARCHIVED - ecoENERGY Retrofit – Homes Program. http://www.nrcan.gc.ca/energy/efficiency/housing/home-improvements/5003

Natural Resources Canada Office of Energy Efficiency. 2011. Energy Efficiency Trends in Canada 1990 to 2009. http://oee.nrcan.gc.ca/publications/statistics/trends11/pdf/trends.pdf

Natural Resources Canada Office of Energy Efficiency. 2003. Survey of Household Energy Use-Detailed Statistical Report. http://oee.nrcan.gc.ca/Publications/statistics/sheu03/index.cfm

Peet, C., and K. Harrison. 2012. Historical Legacies and Policy Reform: Diverse Regional Reactions to BC’s Carbon Tax. *BC Studies* 173: 95-120.

Rosenblum, D. 2008. California leads with proposed carbon fee. *Carbon Tax Center.* http://www.carbontax.org/blogarchives/2008/02/10/california-leads-with-proposed-carbon-fee/

Rivers, N., and B. Schaufele. 2013. Carbon Tax Salience and Gasoline Demand. Working Paper, Ottawa, ON: Graduate School of Public and International Affairs and Institute of the Environment, University of Ottawa.

Stevens, P. 2012. The ‘shale gas revolution’: developments and changes, Chatham House, London, UK.

Sumner, J., L. Bird, and H. Smith. 2009. Carbon taxes: A review of experience and policy design considerations. *National Renewable Energy Laboratory Technical Report*. http://www.nrel.gov/docs/fy10osti/47312.pdf

Sustainable Prosperity. 2011. Canadian Business Preference on Carbon Pricing. http://www.sustainableprosperity.ca/dl329&display.

Torys LLP. 2007. Quebec government to implement carbon tax. *Torys Climate Change Bulletin*. http://www.torys.com/Publications/Documents/Publication%20PDFs/CCB2007-6.pdf

U.S. Department of Energy - Office of Energy Efficiency and Renewable Energy. Weatherization Assistance Program. http://energy.gov/eere/wipo/weatherization-assistance-program

U.S. Bureau of Economic Analysis. Dept. of Commerce. 2013. https://bber.unm.edu/econ/us-pci.htm

Van Loon, J., and A. Mayeda. 2013. Why Canada's Oil Sands Industry Wants CO2 Tax Harper Hates: Energy. *Bloomberg website*. http://www.bloomberg.com/news/2013-02-01/why-canada-oil-sands-industry-wants-co2-tax-harperhates-energy.html.

WTP LLP. 2010. Montgomery county passes nation's first carbon tax. http://www.wtplaw.com/documents/2010/05/montgomery-county-passes-nations-first-carbon-tax

## Appendix

Table A3.1. *Overview of Carbon Tax Policies in North America*

| Country/ Jurisdiction | Start Date | Tax rate | Annual Revenue | Revenue Distribution | Applied to |
|---|---|---|---|---|---|
| Boulder, Colorado | 2007 | $12-13 per metric ton CO2 | $846,885 | Climate mitigation programs | Consumer-electricity only |
| Quebec | 2007 | $3.20 per metric ton of CO2 (C$3.50) | $191 million (C$200 million | Climate mitigation programs | Producer and consumer |
| British Columbia | 2008 | C$10 per metric ton of CO2 in 2008 increasing c$5 annually to C$30 in 2012 | C$1 billion after 2013 | Revenue-neutral-Reductions in other taxes | Producer and consumer |
| BAAQMD, California | 2008 | $0.045 per metric ton of CO2 | $1.1 million (expected) | Climate mitigation programs | Producer |
| Montgomery, Maryland | 2010 | $5 per ton of CO2 | $10 to $15 million | 1. closing budget gap 2. funding county greenhouse gas reduction program | Producer |
| California | Proposed (2015) | undecided | undecided | Revenue- neutral-rebated to taxpayers, particularly low- and medium-income taxpayers, of other taxes | Producer and consumer |

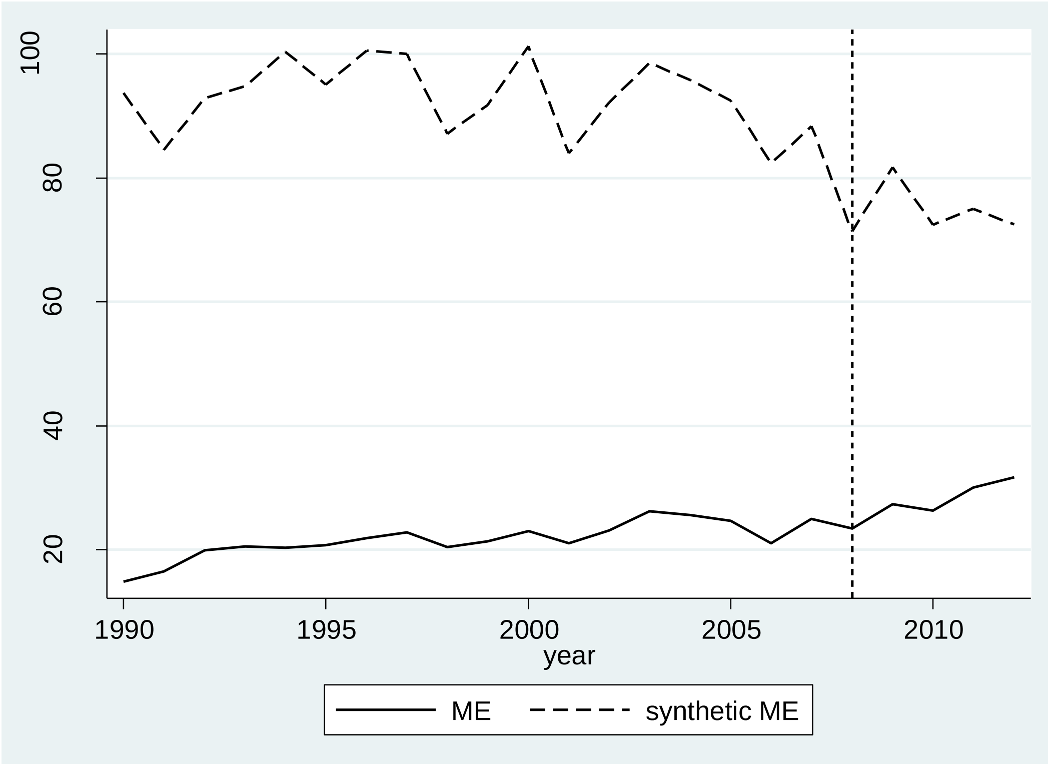



Figure A3.1. Trends in per capita residential natural gas sales: Maine vs. synthetic Maine

Table A3.2. *Weights assigned to construct synthetic Maine*

| States/provinces | weights |
|---|---|
| Quebec | 1 |

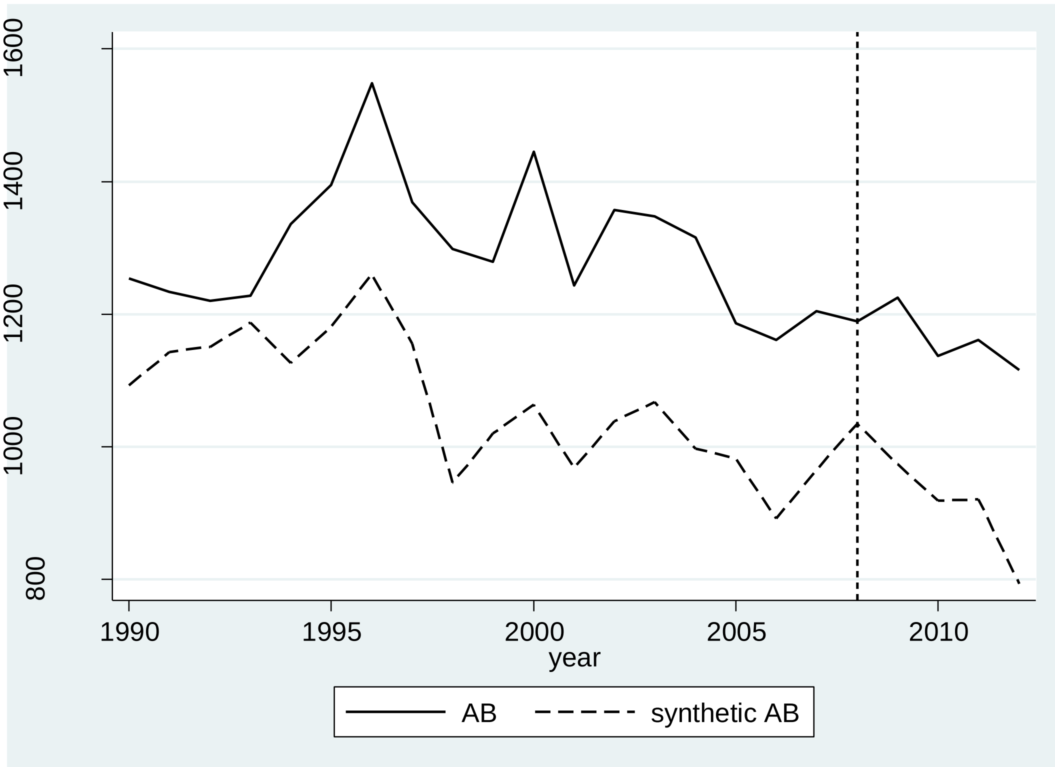



Figure A3.2. Trends in per capita residential natural gas sales: Alberta vs. synthetic Alberta

Table A3.3. *Weights assigned to construct synthetic Alberta*

| States/provinces | weights |
|---|---|
| Illinois | 1 |

Table A3.4. *Estimates of the $DD_i$ estimators (benchmark)*

| States/provinces | Pre-treatment gap | Post-treatment gap | $DD_i$ |
|---|---|---|---|
| Alberta | 232.26 | 211.70 | -20.56 |
| **British Columbia** | **-2.49** | **-21.02** | **-18.53** |
| California | 14.97 | -22.15 | -37.12 |
| Colorado | 25.31 | -16.02 | -41.33 |
| Connecticut | -12.22 | -33.23 | -21.01 |
| Iowa | -7.33 | 5.39 | 12.71 |
| Idaho | -25.22 | 53.82 | 79.04 |

| States/provinces | Pre-treatment gap | Post-treatment gap | $DD_i$ |
|---|---|---|---|
| Illinois | 16.86 | 12.08 | -4.78 |
| Indiana | 5.07 | -16.09 | -21.17 |
| Kansas | 17.08 | 14.96 | -2.12 |
| Massachusetts | 14.87 | 57.84 | 42.98 |
| Manitoba | 24.10 | -20.60 | -44.70 |
| Maine | -71.45 | -45.33 | 26.12 |
| Michigan | -4.92 | 2.49 | 7.41 |
| North Dakota | -8.94 | -0.60 | 8.34 |
| New York | -15.07 | -31.34 | -16.27 |
| Ohio | -7.94 | -21.63 | -13.68 |
| Ontario | -26.28 | -26.24 | 0.04 |
| Oregon | 9.66 | -3.94 | -13.60 |
| Pennsylvania | 6.64 | -15.82 | -22.46 |
| Quebec | -1.45 | -24.68 | -23.23 |
| South Dakota | 0.32 | 12.73 | 12.41 |
| Saskatchewan | 11.34 | 6.32 | -5.03 |
| Wyoming | 17.37 | 24.05 | 6.68 |

## CHAPTER 4

## The Salience of British Columbia's Carbon Taxes to Brown Households

ABSTRACT

I examine the impact of British Columbia's carbon tax on short-run household demand for natural gas. Overall, I find that the carbon tax is no more salient than an equivalent change in the market price. I also find that environmental ideology—as measured by a household-level index of green activities—affects household responses to the carbon tax. For households I classify as "brown," a one dollar increase in the carbon tax reduces natural gas consumption by 10.3 percent. This is substantially larger than the 2.4 percent reduction due to an equivalent change in the market price exhibited by the same set of "brown" households. For households classified as "non-brown," my results suggest that the carbon tax has no effect on natural gas consumption. These results therefore suggest that the carbon tax has effectively reduced natural gas consumption for households that typically do not engage in pro-environmental behaviour. The results also suggest that the tax had no effect on households that were perhaps engaged in voluntary restraint prior to imposition of the carbon tax.

*Keywords*: Carbon tax, tax salience, environmental ideology, natural gas consumption

JEL Classifications: Q41 Q58 H23 H31 D03

### 4.1. Introduction

The British Columbia (BC) provincial government introduced a carbon tax in July 2008. British Columbia's carbon tax is one of the broadest and most comprehensive in the world, and BC is the first North American jurisdiction to impose a broad based carbon tax. The fuels included in the tax base account for about 70 per cent of BC's current greenhouse gas (GHG) emissions including both industry/business and households. Unlike a gasoline tax, the carbon tax is a tax on all carbon dioxide ($CO_2$) equivalent emissions generated from the burning of fuels in BC, including gasoline, diesel, natural gas, fuel oil, propane, and coal purchased within BC. The BC government aims to reduce GHG emissions by 33% below 2007 levels by 2020, through encouraging individuals, businesses, industry and others to use less fossil fuel and reduce their GHG emissions. The carbon tax is revenue- neutral, with recycled revenue supporting reductions in other taxes including personal income tax and business taxes, and providing income tax credits for low income individuals. The initial tax rate was set relatively low; it has been increased every year since first implemented and in 2012 reached $30/tonne of $CO_2$ equivalent emissions.

A couple of recent studies assess the performance of the BC carbon tax. Elgie and McClay (2013) present evidence suggesting that BC’s per capita consumption of fuels subject to the carbon tax fell 19 percent when compared to the rest of Canada. Rivers and Schaufele (2013) present results from an econometric model using monthly (and annual) province-level motor-vehicle fuel consumption. They find that a carbon tax of $0.05 per liter on gasoline caused a 12.5 percent reduction in per capita fuel use through the end of 2011. This result suggests the carbon tax decreased gasoline consumption at a rate more than five times greater than what would be achieved with an equivalent price change. That is, the carbon tax is more salient in reducing gasoline consumption than an equivalent change in the market price.

Understanding how the carbon tax has influenced household natural gas consumption is crucial in evaluating the impact of this policy. In this chapter, I examine the impact of the BC carbon tax on residential natural gas use. I use household-level data on natural gas consumption collected through Statistics Canada's Households and the Environment Survey (HES) and the linked Energy Use Supplement (EUS). This unique dataset was collected in 2007, one year prior to implementation of the carbon tax in BC, and again in 2011, several years after the carbon tax was first implemented. In this chapter, this data is used to (1) assess the salience of BC's carbon tax relative to equivalent changes in the market price of natural gas and (2) examine the extent to which household responses to the carbon tax are dependent on households' environmental ideology.

Several recent empirical studies have examined the relative salience of prices and taxes. Chetty, Looney and Kroft (2009) present evidence that taxes that are easily observed reduce demand significantly more than taxes that are more difficult to observe. Several recent studies find that changes in gasoline taxes are more salient than changes in market prices. Using both time series data and household-level data, Li, Linn, and Muehlegger (2014) examine how gasoline taxes affect gasoline consumption as distinct from tax-exclusive retail gasoline prices. Their empirical evidence suggests that consumers respond more strongly to gasoline tax changes; a 5-cent tax increase reduces gasoline consumption by 0.86 percent, compared with 0.29 percent from an equivalent change in tax-exclusive gasoline prices. Using province-level data, Rivers and Schaufele (2013) find that the BC carbon tax of $0.05 per liter of gasoline caused a 12.5 percent reduction in per capita gasoline use through the end of 2011 in BC. They estimate the effect of an equivalent increase in the market price of gasoline is a 1.8 percent reduction in demand, which suggests the carbon tax is more effective than an equivalent price change.

In this chapter, I use household-level data on natural gas consumption in 2007 and 2011. This data allows me to avoid a couple of potentially confounding factors not accounted for in previous studies. First, using household-level data allows me to control for shifts in the demographic composition of households—this is not possible using province-level data as in Rivers and Schaufele (2013). Second, estimates of the impact of the carbon tax on gasoline use are complicated due to the fact that transport infrastructure projects and other policies (parking taxes and congestion fees) were introduced at roughly the same time as the BC carbon tax. Residential natural gas use was not subject to these province-specific changes to policy and estimates of the impact of the carbon tax on natural gas consumption should provide a cleaner estimate of the impact of the tax and its salience relative to price changes.

Several recent empirical studies examine the role of environmental ideology in mediating choices that influence the environment. A series of papers present evidence that "green" households are more likely to engage in voluntary restraint (Kotchen and Moore 2007, 2008; Kahn 2007; Gallagher and Muehlegger 2011; Kahn and Morris 2009). Most relevant to this chapter, Costa and Kahn (2013) present evidence from a field experiment that nudges—feedback to households on their own and their peers' home electricity usage—are more effective at reducing electricity consumption with political liberals than with conservatives. Costa and Kahn (2013) find that political conservative households that learn they are consuming less electricity than their peers, increase their consumption—referred to as a "boomerang" effect.

Unlike a voluntary nudge, a carbon tax increases the cost of consumption for all consumers. In this chapter I will examine whether or not brown households respond differently than non-brown households to the carbon tax. There are several reasons to expect "brown" consumers will respond differently from "non-brown" or "green" consumers. First, consumers that might be classified as green derive utility from a healthier environment and may therefore voluntarily reduce their consumption to help achieve environmental goals (Pettit and Sheppard 1992). As a consequence of voluntary restraint prior to the tax, green consumers may have less room to reduce carbon consumption and will therefore be less responsive to the carbon tax when compared to brown consumers. Brown households, on the other hand, likely consume more natural gas prior to the tax and therefore have more room to reduce their consumption in response to a carbon tax.

Second, Rivers and Schaufele (2013) suggest the large response to the BC carbon tax that they identify is a result of the carbon tax alleviating "resentment of free-ridership." In the absence of a carbon tax, green consumers engage in less voluntary restraint because they resent the fact that brown consumers do not also engage in voluntary restraint. The brown consumers are free-riding off the efforts of the greens and the greens resent this. The carbon tax forces brown consumers to internalize some of the social costs of carbon, thereby alleviating the greens' resentment of free-ridership. Put another way, environmentally conscious households may be resentful of environmental benefit leakage to brown consumers. This resentment may to some extent reduce their incentives to contribute to conservation efforts. Once a carbon tax is imposed, green consumers may realize there will be less free ridership in carbon consumption and respond by increasing their conservation efforts.

Finally, a carbon tax might serve as a prescriptive signal to consumers that they should reduce their energy consumption. The purpose of the carbon tax is to ensure that a consistent long-term price signal is provided to consumers so that they make the choices (i.e., energy efficient durables, insulation, and installation of programmed thermostat) required to reduce their fuel use (Ministry of Finance, BC). It is possible that green consumers will pay more attention to this signal and respond by reducing their natural gas consumption. Brown consumers, on the other hand, may not respond to this prescriptive signal if they are less concerned about the environment and the signals they receive from the government regarding desirable environmental choices.

In this chapter, household "environmentalism" is assessed based on household activities and choices as revealed by a series of questions in the HES. Pro-environmental/green behaviour refers to behaviour that is perceived to reduce harm to the environment or potentially benefit the environment. Households might also engage in pro-environmental/green behaviour if it will save them money. For example, households might use energy efficient lighting to reduce energy use for environmental reasons, to lower their households' electricity bill, or both. In this chapter, activities that reflect pro-environmental/green attitudes are selected, such as bringing their own shopping bags, purchasing eco-friendly cleaning products, composting, and recycling.

In general, across all households, I find no clear evidence that households respond more to carbon tax changes than to equivalent changes in the tax-exclusive price of natural gas. This suggests that the carbon tax is no more prominent than market price changes in decreasing natural gas consumption. The major finding of this chapter is that responses to the carbon tax depend in part on the environmental ideology of the household. Specifically, "brown" households are more responsive to the carbon tax than non-brown households. As far as I know, this chapter is the first research to investigate household responses to a mandatory restraint, where responses are allowed to vary by environmental ideology. The results in this chapter complement those of Costa and Kahn (2013) who find that political liberals/environmentalists respond positively to a voluntary nudge while political conservatives/non-environmentalists respond negatively to a nudge. The results from this chapter suggest that a voluntary "nudge" is more effective in energy conservation for green/environmentalist households, while a mandatory carbon tax is more effective for brown/non-environmentalist households.

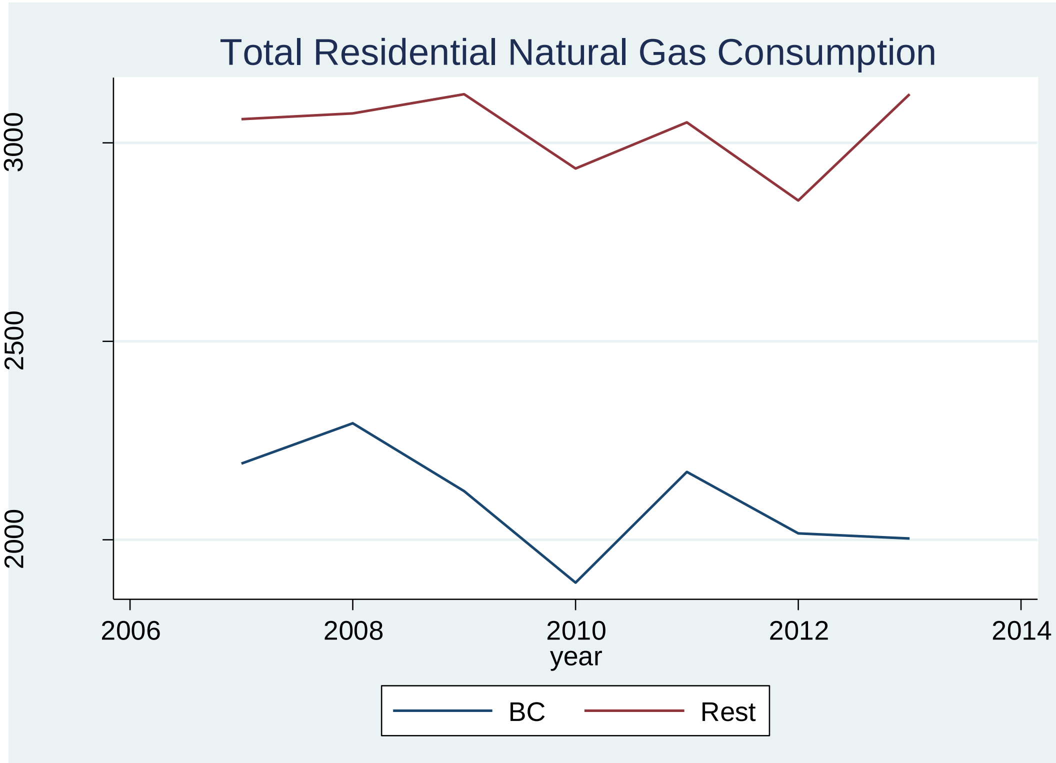
The remainder of this chapter contains four sections. Section 4.2 presents some background on the natural gas market in BC and Canada. The empirical framework is presented in section 4.3. The main results are reported in section 4.4, and section 4.5 provides concluding remarks.

## 4.2. Background

### *4.2.1. Natural gas consumption and price trends*

Natural gas is used primarily for residential house and water heating. It can also be used to fuel large appliances such as stoves, dryers, and barbecues. In Canada, natural gas is the most widely used source of energy in the home, accounting for 45% of total household energy consumption (Statistics Canada, 2011). Natural gas is the principal energy source for households in Alberta (72%), Saskatchewan (68%), Ontario (62%), and British Columbia (54%). It is also an important household energy source in Manitoba and Quebec.[57] Canadian households used a total of 639,203 tons of gigajoule worth of natural gas in their homes in 2011, up 9% from 2007. Figure 4.1 shows the trend in residential natural gas consumption in BC and the rest of Canada from 2007 to 2013. Over this period, residential natural gas consumption declined in BC while for the rest of Canada natural gas consumption increased.

[57] The principal household energy source used in Manitoba and Quebec is hydro electricity.

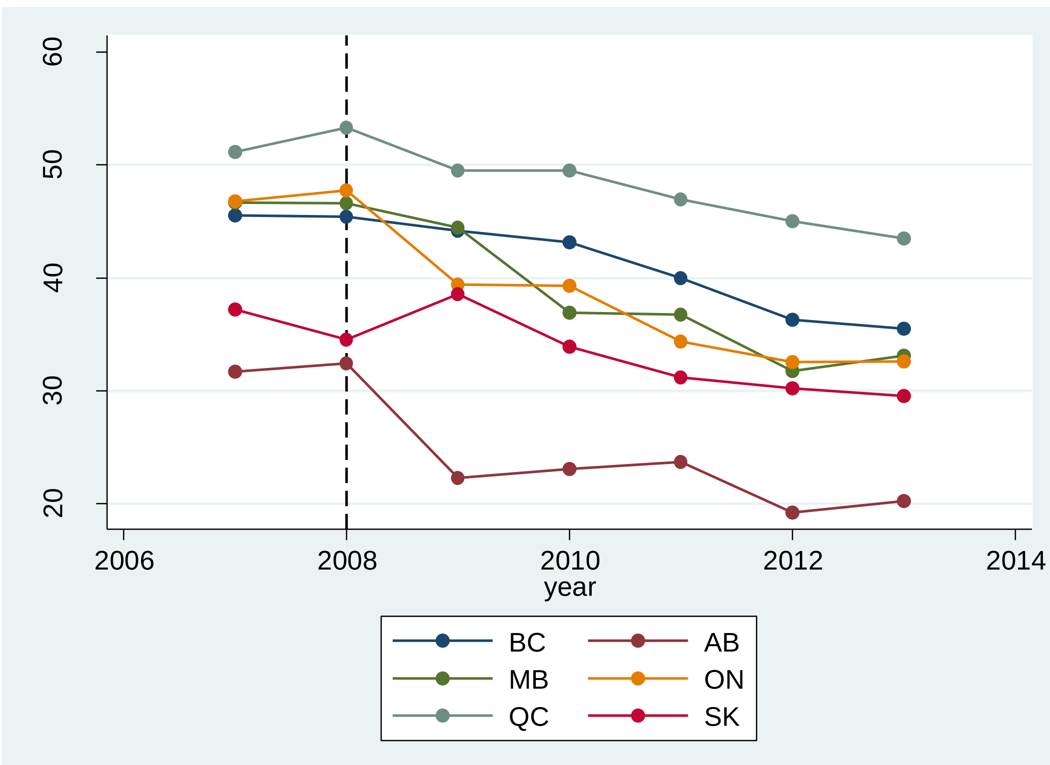



Note: Residential Natural gas consumption in the Rest of Canada is the average residential natural gas consumption in Alberta, Saskatchewan, Manitoba, Ontario and Quebec. Source: CANSIM 1290003

Figure 4.1. Total Residential Natural Gas Consumption

In Canada, the retail cost of natural gas consists of three main components: the charge for the natural gas itself, long-haul pipeline transmission charges, and local distribution and storage charges. In 1985, the Canadian natural gas industry was deregulated, which provided consumers with more choice over many aspects of their gas purchases (Natural Resource Canada, 2013). Households can purchase natural gas under variable or fixed rates. Fixed rate contracts are sold by energy retailers and allow homeowners to lock in prices for the life of the contract, which may range from one to five years. Fixed rates are not regulated by the government. Variable rates for natural gas are provided by local distributors and are regulated by the government.

Currently, variable rates fluctuate on a monthly or quarterly basis. Roughly one quarter of homes are on fixed-rate plans and the remainder purchase natural gas through variable rates (Global News, 2014). Figure 4.2 displays the annual tax-exclusive residential price of natural gas in six provinces. Over the past 10 years, the total costs for natural gas have fluctuated mainly due to changes in the cost of the commodity (National Energy Board). In general, provinces closest to natural gas supply have lower prices. Since 2000, Alberta has had the lowest total cost for natural gas while Quebec has had the highest total cost. Overall, natural gas prices for residential customers fell slightly in the most recent 5 years.




Source: CANSIM 129-0003

Figure 4.2. Annual Residential Natural Gas Prices, by Province

Several recent papers have estimated the price elasticity of demand for natural gas. As expected, the demand for natural gas appears to be price inelastic. Using micro-data from the Energy Information Administration (EIA) in the U.S., Mansur et al. (2008) find the own price elasticity of natural gas demand is -0.8. Using U.S. Census micro-data, Davis and Kilian (2011) report household natural gas price elasticities of demand that range from -0.34 to -0.10. Using time series data from 1970 to 2006, Ryan et al. (2012) report the average price elasticity of natural gas demand in Canada is -0.66. There is therefore substantial variation in previous estimates of the price elasticity of demand for natural gas, yet all find inelastic.

*4.2.2. Demand-side management of residential energy use*

Energy taxes have been imposed on stationary use sources including fuel oils, natural gas, and coal in several European countries in order to reduce GHG emissions associated with energy consumption. In the US, many state and federal policies have used financial incentives to reduce demand for energy, including subsidies for adoption of energy-efficient durables such as home appliances, and energy rate structures that penalize excessive use and reward home power generation. In Canada, rebates for energy-saving home renovations through the ecoENERGY Retrofit-Home program helped homeowners save an average of 20 per cent on their home energy use (Natural Resource Canada, 2014).

On February 19, 2008, the BC provincial government announced its intention to implement a carbon tax beginning on July 1, 2008. Prior to February 19, there was no public acknowledgement that carbon taxes were a prospective policy option. The carbon tax has been gradually increased since 2008. It was initially set at \$10 per tonne $CO_2$ equivalent emission ($tCO_2e$) and set to increase by \$5/ $tCO_2e$ each July 1 until 2012. It reached its maximum and current level of \$30/ $tCO_2e$ on July 1, 2012. Since different fuels generate different amounts of

GHG when burned, \$30/ $tCO_2e$ must be translated into tax rates for each specific type of fuel. Table 4.1 shows the per unit rates for natural gas. Effective July 1, 2012 the rate for natural gas is 149.64 cents per GJ.

Table 4.1. *BC carbon tax rates on natural gas*

| Date | Carbon Tax (\$/tonnes) | Carbon Tax on Natural Gas (\$/GJ) | Residential Natural Gas Price in BC (\$/GJ) |
|---|---|---|---|
| July 1, 2008 | 10 | 0.50 | 13.56 |
| July 1, 2009 | 15 | 0.75 | 13.20 |
| July 1, 2010 | 20 | 1.00 | 13.14 |
| July 1, 2011 | 25 | 1.25 | 12.53 |
| July 1, 2012 | 30 | 1.50 | 11.55 |

Source: British Columbia Ministry of Finance Tax Bulletin (June, 2014). Residential price of natural gas in BC is from CANSIM table 1290003.

## 4.3. Identifying Responses to BC's Carbon Tax

In this section, I specify a model to test the overall impact of the carbon tax on household natural gas consumption. This is followed by the specification of a model of heterogeneous responses to the carbon tax, where brown households may respond differently from other households. I assume throughout that in the short run, consumers bear the entire burden of the tax, and the carbon tax-exclusive price is not affected by the introduction of the carbon tax.[58]

### 4.3.1. *Econometric model*

*A. Overall Impact*

I specify the following tax salience model to examine responses to the BC carbon tax and the market price of natural gas:

$$\log(q_{ht}) = \gamma_0 + \gamma_1 p_{ht} + \gamma_2 \tau_{ht} + \boldsymbol{X}_{ht}\theta + \epsilon_{ht} \tag{24}$$

where $\gamma_i$ $(i = 0,1,2)$ and θ are parameters to be estimated; $q_{ht}$ is monthly consumption of natural gas by household $h$ at time $t$; $p_{ht}$ is the carbon tax-exclusive price of natural gas; $\tau_{ht}$ is

[58] Marion and Meuhlegger (2011) find strong evidence that state taxes are fully (and rapidly) passed through to consumers.

the carbon tax; the matrix $\boldsymbol{X}_{ht}$ includes household characteristics, house characteristics, and climate variables; and $\epsilon_{ht}$ is the error term. Equation (24) is specified as a log-linear model. This implies that the coefficients of interest, $\gamma_1$ and $\gamma_2$, are interpreted as semi-elasticities of price and carbon tax, respectively.

*B. Heterogeneous responses to the carbon tax*

I investigate whether or not "brown" households respond to the carbon tax differently from other households with the following model:

$$\log(q_{ht}) = \varphi_0 + \varphi_1 p_{nt} I_{bh} + \varphi_2 \tau_{ht} I_{bh} + \varphi_3 p_{ht} I_{nh} + \varphi_4 \tau_{ht} I_{nh} + \boldsymbol{X}_{ht}\theta + \mu_h \quad (25)$$

where $\varphi_i$ $(i = 0, \dots 4)$ and θ are parameters to be estimated; $I_{bh}$ is the brown household indicator with $I_{bh} = 1$ if the household is brown, and $I_{bh} = 0$ otherwise; $I_{nh}$ is the non-brown household indicator with $I_{nh} = 1$ if the household is non-brown, and $I_{nh} = 0$ otherwise; and $\mu_h$ is the error term. The parameters $\varphi_1$ and $\varphi_2$ are the price and carbon tax semi-elasticities for brown households, while $\varphi_3$ and $\varphi_4$ are the price and carbon tax elasticities for the non-brown households. For each household type, if the tax semi-elasticity of demand is negative and greater than the price semi-elasticity of demand, then I can conclude the carbon tax is more effective than an equivalent price change. Further, I can also investigate if brown households respond more to the carbon tax than non-brown households by a test of the equivalence of the two carbon tax semi-elasticities, $\varphi_2 = \varphi_4$.

4.3.2. *Data and Summary Statistics*

The raw data comes from micro-data files of the 2007 and 2011 HES and EUS, which are linked by household and designed as cross-sectional data sets.[59] The target group is a geographically representative sample from across Canada (excluding households located in the

[59] The master files are accessed from the University of Manitoba's Research Data Center (RDC) through an agreement with Statistics Canada. Same households participate in both surveys, and each is assigned a unique ID number.

Yukon, Northwest Territories and Nunavut, households located on Indian reserves or Crown lands, and households of armed forces personnel). The selected respondents completed the survey via telephone interviews. The HES consists of more than 300 questions pertaining to demographic information, dwelling and occupant characteristics, energy use, water, fertilizer and pesticide use, recycling and composting activity, indoor environmental and air quality, and environmental purchasing decisions. The EUS includes questions about dwelling characteristics, household appliances, electrical devices, and heating and cooling equipment. The EUS also obtains permission to obtain monthly energy consumption from each household during the 2007 and 2011 calendar years directly from each household energy utility.

I first merge the HES with the EUS through common household identification numbers. Next, I restrict the sample to households that use natural gas as their major heating source. Households that rent their place of residence, households in the Atlantic provinces (natural gas is rarely used as a heating source in Atlantic Canada), and households with zero income are removed from the sample (about 8%). After dropping these households, the sample size is 4,800 households.

*A. Price of natural gas*

The EUS records monthly energy consumption. However, it provides no information about the natural gas price each household faces. Since the natural gas price each household pays is unobservable, I estimate models using both variable rates and fixed rates. Variable rates are calculated based on Statistics Canada, CANSIM table 129-0003, which provides monthly information on sales unit prices in each province, calculated by dividing sales revenue by sales volume.[60]

[60] The data from CANSIM 1290003 is generated from a monthly survey of Gas Utilities/Transportation and Distribution Systems. This monthly survey collects data on the activities of Canadian natural gas distributors and transporters.

Most of the provinces in Canada adopt a quarterly variable rate except for Alberta, where the local distributor adopts a monthly rate.[61] I report results from variable rate and fixed rate specifications. The variable rate specifications use monthly sales prices for Alberta and quarterly sales prices for the rest of Canada. Fixed rates are calculated under the assumption that prices vary by province, but are constant within each year. I use a provincial annual price based on the weighted average price reported by Statistics Canada in CANSIM table 129-0003.

*B. Household brown-non brown indicators*

The impact of environmental ideology on "pro-environmental" actions and choices of households has been examined in several recent papers. The approach used to classify households as "brown" versus "green" is a central concern in each of these studies. Kotchen and Moore (2007) measure environmental concern using a survey that assesses attitudes toward the environment, based on what is referred to as the "New Ecological Paradigm."[62] Other studies use registration in environmental organizations or political parties to proxy for environmentalism. Kotchen and Moore (2008) use registration in environmental organizations to classify households as either conservationists or non-conservationists and find that conservationists consume less conventional electricity than non-conservationists. Kahn (2007) uses neighborhood-level Green Party share of registered voters as his primary measure of environmentalism. He finds that environmentalists in California make "greener" transportation choices than the average consumer. Costa and Kahn (2013) classify households that are registered with liberal political parties, that live in communities with a large liberal share of the vote, that have previously signed up to purchase energy from renewable resources, and that

[61] Manitoba, Ontario, and British Columbia use variable rates varied by quarter.

[62] Kotchen and Moore (2007) conduct a survey to measure individuals' attitude towards the environment based on level of agreement with statements such as "the balance of nature is very delicate and easily upset," "plants and animals have as much right as humans to exist," and "humans will eventually learn enough about how nature works to be able to control it."

donate to environmental causes as environmentalists. Gallagher and Muehlegger (2011) use state-level per-capita Sierra Club membership as a proxy for environmental ideology and military participation as a proxy for environmental preference.

In this chapter, I select activities that reflect pro-environment/green attitudes. I use the following questions from the HES:

1. In the past 12 months, how often did your household purchase environmentally friendly or 'green' cleaning products?
2. In the past 12 months, how often did your household use your own bags or containers to carry your groceries?
3. During the past 12 months, did your household separate any kitchen waste from the rest of your garbage and put it out for compost collection, take it to a depot, or put it in a compost pile or bin?
4. During an average week in the past 12 months, how much recyclable paper/glass/plastic/metal waste did you recycle?

These questions are used to construct a revealed preference index of pro-environmental behaviour. Questions 1 and 2 relate to household purchasing decisions. Responses are based on a five-point Likert scale, including "always," "often," "sometimes," "rarely," and "never." Questions 3 and 4 relate to composting and recycling. Both of these are activities that require an investment of time and effort. Responses to question 3 are limited to a "yes" or "no" choice. Responses to question 4 are based on a 4-point Likert scale, including "all", "almost","some", and "none." To evaluate these questions using the same measurement scale, all the responses are adjusted to take on a value of one or zero. For questions 1 and 2, responses of "always" or "often" are coded as 1, and responses of "sometimes," "rarely," and "never" are coded as 0. For question 3, responses with "yes" are coded as 1, and with "no" are coded as 0. For question 4, responses with "all" are coded as 1, and the rest are coded as 0. Each of the four questions are given equal weight in the construction of the index. The green index for each household is the sum of all the responses to the above questions, ranging from 0 to 4, where "4" represents the most environmentally conscious household according to my index and "0" the least. I define households with an index less than or equal to 1 as brown. Using this definition, approximately 34% of the survey sample is brown.

*C. Household demographics*

For household demographic characteristics, I include household income, the number of household members, a dummy variable indicating whether or not a senior lives in the house, and a dummy variable indicating whether the household has children under the age of 12. Previous investigations indicate that household energy use is related to household size, income, and other demographic variables, such as the number of seniors in a household (Fritzsche, 1981, O'Neill and Chen, 2002, Costa and Kahn, 2010, and Brounen, Kok and Quigley, 2012). In this chapter, I acknowledge that residential natural gas consumption is also a function of demographic composition including the number of household members, family income, and the presence of seniors or children.

*D. Heating degree days*

I use heating degree days (HDD) as an explanatory variable to capture the impact of temperature on energy consumption. Daily heating degree-days are calculated based on the number of degrees Celsius that the mean temperature is below 18 ℃. If the temperature is greater than or equal to 18 ℃, then the HDD will be zero for that day. Values below the base of

18 ℃ are used to estimate the heating requirements of buildings. Monthly HDD for a 30-day month are calculated as follows:

$$HDD_k = \sum_{d=1\ldots30} 18 - T_{kd} \qquad if\ T_{kd} < 18 \tag{26}$$

where $HDD_k$ is HDD in location *k*; and $T_{kd}$ is the average outdoor temperature in location *k* on day *d*. I use data from Environment Canada to calculate $HDD$. Households with a valid Census Metropolitan Area (CMA) code (N=2600) are assigned the climate data for that CMA. For households living in non-CMA areas (N=2200) HDD are calculated based on average climate data for the province.

*E. Dwelling characteristics*

Following Brounen, Kok and Quigley (2012), I expect that both physical dwelling characteristics and household demographic characteristics affect residential energy consumption. For dwelling characteristics, I include total heating area in square feet (excluding garage and basement), year the dwelling was built, dummy indicators for heated garage or basement, type of fuel used for water heating, dummy indicators for supplemental heating, the age of the furnace (i.e., less than or equal to 5 years, greater than 5 years but less than or equal to 10 years, greater than 10 years but less than or equal to 15 years, greater than 15 years but less than or equal to 20 years, greater than 20 years but less than or equal to 25 years, and greater than 25 years), age of windows (i.e., less than or equal to 5 years, greater than 5 years but less than or equal to 10 years, greater than 10 years and less than or equal to 15 years, and greater than 15 years), the type of dwelling (including single detached, double, row and terrace, duplex and apartment), and dummy indicators for programmable thermostats and attic insulation.

*F. Time and geographic fixed effects*

I include year and month fixed effects in the baseline regressions. The year fixed effects controls for time-varying factors common to all households in the sample. These might include federal policies that affect household natural gas consumption. For example, the former federal ecoENERGY Retrofit Homes program from April 2007 to March 2012 provided grants of up to $5,000 to help homeowners make their houses more energy efficient and reduce the burden of high energy costs (Natural Resources Canada- ecoENERGY Retrofit – Homes Program, 2014). This program should decrease home energy consumption. The incorporation of year fixed effects controls for the potential impact of this type of program. Month fixed effects are also included as controls for systematic monthly variation in natural gas consumption not picked up by HDD.

I also include census metropolitan area (CMA) fixed effects in the baseline regression to capture regional heterogeneity in demand for natural gas, possibly due to variation in the housing stock, local climate, consumer preferences, or variation in local government policy. According to Statistics Canada, a CMA is a group of census subdivisions comprising a large urban area (the "urban core") and the surrounding "urban fringes" with which it is most closely integrated. A CMA must have a total population of at least 100,000 of which 50,000 or more live in the core. According to 2011 statistics, there are 33 CMAs in Canada. Their populations vary from 118,975 to 5,583,064. There are 4 CMAs in BC: Vancouver, Victoria, Kelowna, and Abbotsford.

Table 4.2 provides detailed summary statistics on natural gas consumption, demographic characteristics, and dwelling characteristics of sample households varied by environmental ideology. The average household in the sample consumes 8.29 GJ of natural gas in a month, which is equivalent to consumption of 99.48 GJ annually. There is clearly variation in consumption according to household environmental ideology. As a comparison: per household natural gas consumption for brown households is 8.33 GJ and 8.20 GJ for non-brown households. This suggests that, on average, brown households consume more natural gas than non-brown households.

The average family size of the sample of homeowners is 2.85 persons. The brown households have a smaller household size than the non-brown households. Approximately one third of the households have seniors. There is no significant difference in the percentage of seniors between brown and non-brown households. In addition, about 23% of the families have kids under 12, and brown households tend to have fewer children than non-brown households. In terms of household income, 13% of the sample have a family income less than $40,000, 31% of the households have an income greater than $40,000 and less than $80,000, and 56% of the households have income greater than $80,000. There is little difference between brown households and non-brown households in the income distribution.

Regarding dwelling characteristics, the data indicate that about 34% of the families in the sample installed a programmable thermostat and 74% of households have their attics insulated. For these thermal and quality characteristics, non-brown households are more likely to install a programmable thermostat and insulate their attics. For the age of the windows, most of the households (48%) have windows aged less than 5 years, and only 8% of the households have windows aged greater than 15 years. Browns tend to have fewer windows aged greater than 10 and less than 15 years, but tend to have more windows aged greater than 15 years. Approximately 85% of the households use natural gas as water heating, and 50% of households use supplement heating. Around 28% of the households heat a garage during the winter time.

When distinguished by environmental ideology, the non-brown households tend to use more supplement heating and are more likely to use natural gas for water heating, whereas brown households are more likely to heat their garage in winter. The average heating area, excluding the garage and basement, in the sample is 1679 cubic feet. Non-brown households tend to have a larger heating area than brown households. The data indicate that most of the families (59%) have heating equipment that is more than 25 years years old, and around 22% of the households in the sample have heating equipment that is less than 10 years old. Brown households tend to be more likely to have heating equipment aged less than 10 years compared with non-brown households. The average building year in the sample is 1974. Brown households tend to live in newer buildings than non-brown households. In terms of the dwelling type, 79% of the sample resides in a single detached house. Only 7% of the households in the sample live in an owned apartment. There is not much difference in dwelling type between brown households and non-brown households.

Table 4.2. *Summary statistics*

| | Whole sample | | Brown Households | | Non-brown Households | |
|---|---|---|---|---|---|---|
| | Mean | Std. Dev | Mean | Std. Dev | Mean | Std. Dev |
| Monthly gas consumption (GJ) | 8.29 | 6.97 | 8.33 | 6.73 | 8.20 | 7.09 |
| Price of natural gas ($/GJ) | 12.55 | 3.16 | 12.32 | 3.10 | 12.68 | 3.18 |
| ***Household demographics*** | | | | | | |
| Seniors (Yes=1) | 0.31 | 0.46 | 0.31 | 0.48 | 0.31 | 0.44 |
| Kids under 12 (Yes=1) | 0.23 | 0.45 | 0.22 | 0.48 | 0.24 | 0.43 |
| Household size | 2.85 | 1.38 | 2.83 | 1.42 | 2.85 | 1.36 |
| *Income* | | | | | | |
| Income ≤ $40,000 | 0.13 | 0.34 | 0.13 | 0.34 | 0.13 | 0.34 |
| $80,000 ≥Income > $40,000 | 0.31 | 0.46 | 0.31 | 0.46 | 0.31 | 0.46 |
| Income >$80,000 | 0.56 | 0.50 | 0.56 | 0.50 | 0.56 | 0.50 |
| ***Heating degree days (monthly)*** | | | | | | |
| HDD | 356.29 | 284.14 | 373.84 | 290.05 | 346.99 | 280.51 |
| HDD square | 207,679 | 248,194 | 223,885 | 268,366 | 199,082 | 236,351 |
| ***Dwelling Characteristics*** | | | | | | |
| Programmable thermostat (Yes=1) | 0.34 | 0.47 | 0.22 | 0.42 | 0.40 | 0.49 |
| Attic insulated (Yes=1) | 0.74 | 0.44 | 0.73 | 0.44 | 0.75 | 0.43 |

| | Whole sample | | Brown Households | | Non-brown Households | |
|---|---|---|---|---|---|---|
| | Mean | Std. Dev | Mean | Std. Dev | Mean | Std. Dev |
| *Age of windows* | | | | | | |
| Age ≤5 years | 0.48 | 0.44 | 0.49 | 0.44 | 0.48 | 0.43 |
| 10 years ≥Age> 5 years | 0.25 | 0.26 | 0.25 | 0.23 | 0.26 | 0.26 |
| 15 years ≥Age> 10 years | 0.19 | 0.21 | 0.17 | 0.20 | 0.21 | 0.21 |
| Age> 15 years | 0.08 | 0.20 | 0.09 | 0.12 | 0.05 | 0.20 |
| Natural gas water heater (Yes=1) | 0.85 | 0.35 | 0.82 | 0.38 | 0.87 | 0.34 |
| Supplemental heating (Yes=1) | 0.50 | 0.50 | 0.46 | 0.50 | 0.51 | 0.50 |
| Garage heated (Yes=1) | 0.28 | 0.44 | 0.29 | 0.47 | 0.26 | 0.41 |
| Basement heating area (cubic feet) | 877.54 | 502.51 | 896.01 | 504.01 | 867.74 | 501.45 |
| Total heating area (cubic feet)[63] | 1679.23 | 700.61 | 1627.35 | 675.67 | 1706.74 | 711.97 |
| *Age of heating system* | | | | | | |
| Age ≤5 years | 0.10 | 0.27 | 0.11 | 0.29 | 0.08 | 0.27 |
| 10 years ≥Age> 5 years | 0.12 | 0.33 | 0.13 | 0.34 | 0.12 | 0.32 |
| 15 years ≥Age> 10 years | 0.09 | 0.28 | 0.07 | 0.26 | 0.10 | 0.29 |
| 20 years ≥Age> 15 years | 0.06 | 0.24 | 0.07 | 0.25 | 0.06 | 0.24 |
| 25 years ≥Age> 20 years | 0.04 | 0.20 | 0.05 | 0.22 | 0.04 | 0.19 |
| Age >25 years | 0.59 | 0.49 | 0.57 | 0.50 | 0.60 | 0.49 |
| Year built | 1974 | 26.86 | 1977 | 24.77 | 1972 | 27.75 |
| *Dwelling Type* | | | | | | |
| Single Detached | 0.79 | 0.37 | 0.80 | 0.36 | 0.79 | 0.38 |
| Double | 0.06 | 0.25 | 0.04 | 0.22 | 0.07 | 0.26 |
| Row and Terrace | 0.06 | 0.25 | 0.06 | 0.25 | 0.05 | 0.25 |
| Duplex | 0.02 | 0.15 | 0.02 | 0.14 | 0.02 | 0.16 |
| Apartment | 0.07 | 0.19 | 0.07 | 0.21 | 0.06 | 0.19 |

## 4.4. Results

In this section I present the results for (1) the basic model that ignores heterogeneous household responses and (2) the model that incorporates heterogeneity due to environmental ideology. I conduct and present a series of robustness checks for each of these models.

### *4.4.1. Overall impact*

Table 4.3 reports results from the baseline specification of the model in equation (1). I regress the log of household natural gas consumption on the price of natural gas, the carbon tax, demographic characteristics, dwelling characteristics, HDD, and year, month, and CMA fixed

[63] Basement and garage are excluded.

effects. All prices and the carbon tax are adjusted by the Consumer Price Index (CPI) in all specifications. Sample weights are used to obtain robust standard errors.[64]

The baseline specification reported in Table 4.3 suggests that natural gas demand is own price inelastic. The semi-elasticity is -0.026, and the corresponding elasticity is -0.27.[65] This implies that a one dollar increase in the market price decreases natural gas consumption by 2.6%. The estimates of own price elasticity of demand in this chapter are consistent with Davis and Kilian (2011), who estimate price elasticities of natural gas demand in the US ranging from -0.34 in 1980 to -0.10 in 2000 using Energy Information Administration (EIA) self-reported data.

The estimated coefficient on the carbon tax is -0.04. This implies that a one dollar increase in the carbon tax decreases natural gas consumption by 4%. To test whether the overall impact of the carbon tax is more salient than changes in market prices, an F-test is used to test the null hypothesis that $\gamma_1 = \gamma_2$. The test statistic is 0.78, so we fail to reject the null hypothesis that the carbon tax has the same impact as an equivalent price change. That is, with respect to natural gas consumption, the impact of a one dollar increase in the carbon tax is no more salient than a one dollar increase in price. This result contrasts with much of the prior work on the salience of taxes versus prices. Of particular relevance to this chapter, Rivers and Schaufele (2013) find that, with respect to automobile gasoline purchases, the BC carbon tax is roughly five times more salient than an equivalent price change.

Temperature is among the most important determinants of natural gas consumption. I use $HDD$ and $HDD^2$ to capture the impact of temperature on natural gas consumption. I find a positive relationship between $HDD$ and natural gas consumption. When *HDD* increases by one day natural gas consumption increases by 0.1%. A negative sign of $HDD^2$ implies the relation

[64] In HES and EUS, the given sample weight is a probability weight.
[65] Elasticity of natural gas is equal to semi-elasticity times average price of natural gas.

between $HDD$ and natural gas consumption is nonlinear. A two-way scatter plot between natural gas consumption and *HDD* is concave, and does not reach the turning point within the *HDD* in my sample.

Dwelling characteristics also play an important role in explaining household natural gas consumption. As expected, dwellings with larger heating area (excluding basement and garage) consume more natural gas. A one square foot increase in heating area increases natural gas consumption by 0.009%. Households that use natural gas to heat their garage or basement and use natural gas water heaters consume more natural gas. The age of the furnace influences energy consumption: all else equal, I find that a household with an older furnace uses more natural gas, which is consistent with the fact that the heating efficiency of furnaces has increased over time. I expected that houses with older windows would use more natural gas. However, I do not find the age of windows has a significant impact on natural gas consumption. It is possible that households with older windows take greater care to insulate their windows in the winter. The EUS records the year the dwelling was constructed. I find that newly built dwellings use less natural gas, reflecting the use of improved building materials and improved construction standards for recently built houses. Households living in single detached, double, or row and terrace dwellings tend to use more natural gas than households living in apartments, perhaps because of shared walls in apartments and other scale effects. I find clear evidence that the presence of attic insulation and programmable thermostats reduces natural gas consumption. Finally, I find that houses that have been recently retrofitted consume less energy, perhaps due to retrofits that improve energy efficiency.

It is widely acknowledged that household energy consumption is a function not only of climate and the physical structure of the building but also household demographics. I find that larger households consume more natural gas: an increase in household size by one member increases natural gas consumption by 3.6%. Households with seniors tend to use more natural gas and households with children less than 12 years old tend to use less natural gas. Households with an annual income less than $40,000 tend to use less natural gas than higher income households (whose annual incomes exceed $80,000).

Table 4.3. *Effect of Price and Carbon Taxes on Household Natural Gas Consumption - baseline model*

| | Coefficients | Robust Std. Err |
|---|---|---|
| Price ($\gamma_1$) | -0.026*** | 0.004 |
| Carbon tax ($\gamma_2$) | -0.040* | 0.023 |
| ***Household demographics*** | | |
| Seniors | 0.049*** | 0.012 |
| Kids under 12 | -0.035*** | 0.013 |
| Household size | 0.036*** | 0.004 |
| *Income* | | |
| Income <= 40,000 | -0.032*** | 0.009 |
| 80,000>=Income > 40,000 | -0.003 | 0.007 |
| Income >80,000 | omitted | |
| ***Heating degree days*** | | |
| HDD | 0.001*** | 0.0001 |
| HDD square | -9.39e-07 *** | 7.54e-08 |
| ***Dwelling Characteristics*** | | |
| Programmable thermostat | -0.041*** | 0.011 |
| Attic insulated | -0.025*** | 0.008 |
| *Age of windows* | | |
| Age $\leq$5 years | omitted | |
| 10 years $\geq$Age> 5 years | -0.078 | 0.052 |
| 15 years $\geq$Age> 10 years | 0.011 | 0.04 |
| Age> 15 years | -0.002 | 0.031 |
| Natural gas water heater | 0.025*** | 0.007 |
| Supplemental heating | -0.076*** | 0.012 |
| Garage heated | 0.043*** | 0.013 |
| Basement heated | 0.00009*** | 8.63e-06 |
| Total heating area (excluding garage and basement) | 0.0002*** | 7.51e-06 |
| *Age of heating system* | | |
| Age $\leq$5 years | omitted | |
| 10 years $\geq$Age> 5 years | 0.010 | 0.011 |
| 15 years $\geq$Age> 10 years | 0.039*** | 0.014 |
| 20 years $\geq$Age> 15 years | 0.066*** | 0.012 |
| 25 years $\geq$Age> 20 years | 0.104*** | 0.017 |
| Age >25 years | 0.031*** | 0.009 |

| | Coefficients | Robust Std. Err |
|---|---|---|
| Year built | -0.0003** | 0.00016 |
| *Dwelling Type* | | |
| Single Detached | 0.282*** | 0.046 |
| Double | 0.228*** | 0.050 |
| Row and Terrace | 0.141*** | 0.047 |
| Duplex | 0.067 | 0.049 |
| Apartment | omitted | |
| ***Geographic and time fixed effects*** | | |
| CMA | Yes | |
| Year | Yes | |
| Month | Yes | |
| **Number of households** | 4800 | |
| **Number of observations** | 51600 | |
| $R^2$ | 0.69 | |
| **Probability of F- test:** $\gamma_1 = \gamma_2$ | 0.65 | |

Note: Sampling weights are used in all regressions.*, **, and *** denote significance at the 10%, 5% and 1% levels

Table 4.4 displays results from a series of robustness checks using different sets of geographic and time fixed effects. Ten models are presented. Controls for demographics, housing characteristics, and HDD are included in each of the model specifications reported in Table 3. The coefficients on these control variables are not influenced by the robustness checks and are omitted from Table 4.4 to conserve space. Models (1) through (5) use a variable rate as the natural gas price and models (6) through (10) use an annual fixed rate as the natural gas price. Both model (1) (my baseline specification) and model (6) incorporate CMA, year, and month fixed effects. Models (2) and (7) use CMA fixed effects and year fixed effects. Models (3) and (8) apply CMA fixed effects and month fixed effects. Models (4) and (9) contain year and month fixed effects. Finally, models (5) and (10) use CMA fixed effects and year-month interaction fixed effects.

Across all specifications, the coefficients on the price of natural gas are consistent with the results in the baseline specification. I find mixed results for the carbon tax. In specifications (1), (2), (3), (7) and (8) the estimated coefficient on the carbon tax is negative and statistically significant.  The carbon tax is more salient than the price in models (2) and (3). However, for the remainder of the specifications, I find that the carbon tax is no more salient than equivalent price changes. The most conservative result in Table 4.4 (specification (10)) suggests that households did not respond to the carbon tax.

Table 4.4. *Estimates for the effect of Price and carbon taxes on natural gas consumption using aggregated data- robustness check*

| | Variable price | | | | | Annual fixed price | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1)-baseline | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Price ($\gamma_1$) | -0.026*** | -0.025*** | -0.018*** | -0.030*** | -0.026*** | -0.056*** | -0.042*** | -0.009** | -0.030*** | -0.058*** |
| | (0.004) | (0.003) | (0.002) | (0.002) | (0.004) | (0.011) | (0.011) | (0.005) | (0.002) | (0.011) |
| Carbon tax ($\gamma_2$) | -0.040* | -0.097*** | -0.051*** | -0.017 | -0.035 | -0.022 | -0.086*** | -0.056*** | -0.017 | -0.016 |
| | (0.023) | (0.021) | (0.018) | (0.018) | (0.020) | (0.021) | (0.023) | (0.018) | (0.018) | (0.020) |
| ***Geographic and time fixed effects*** | | | | | | | | | | |
| CMA | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | | Yes |
| Year | Yes | Yes | | Yes | | Yes | Yes | | Yes | |
| Month | Yes | | Yes | Yes | | Yes | | Yes | Yes | |
| Year*month | | | | | Yes | | | | | Yes |
| **Prob of F- test:** $\gamma_1 = \gamma_2$ | 0.65 | 0.001 | 0.076 | 0.12 | 0.908 | 0.83 | 0.151 | 0.101 | 0.491 | 0.74 |

Note: All regressions include the control variables- household characteristics, dwelling characteristics, and HDD. Sampling weights are used in all regressions.*, **, and *** denote significance at the 10%, 5% and 1% levels. Standard errors are in parentheses.

*4.4.2. Heterogeneous response to the carbon tax*

*A. Baseline Models*

In this section, I present results that allow the response to the carbon tax to vary by type of household, where households are differentiated on the basis of environmental ideology as either brown or non-brown. The baseline specification in this section uses a variable rate for the price of natural gas and a semi-log specification, controlling for the full suite of household demographics, dwelling characteristics, HDD, and CMA, year, and month fixed effects.

Table 4.5 reports the results from the baseline model. A one dollar increase in the market price is estimated to reduce natural gas consumption in non-brown households by 2.5% and the corresponding price elasticity of demand is -0.25. For brown households, a one dollar increase in the price of natural gas reduces consumption by 2.4% and the corresponding price elasticity is -0.24. As in the baseline specification reported in Table 4.3, the price elasticity of demand for natural gas is inelastic. There is also no statistically significant difference between the price elasticity of demand for brown and non-brown households.

Table 4.5. *Estimates of the tax salience model varied by environmental ideology*

| | Coefficients | Robust Std. Err |
|---|---|---|
| Price*brown indicator ($\varphi_1$) | -0.024*** | 0.004 |
| Carbon tax*brown indicator ($\varphi_2$) | -0.103*** | 0.035 |
| Price*non-brown indicator ($\varphi_3$) | -0.025*** | 0.005 |
| Carbon tax*non-brown indicator ($\varphi_4$) | 0.020 | 0.026 |
| ***Household demographics*** | | |
| Seniors | 0.049*** | 0.012 |
| Kids under 12 | -0.035*** | 0.013 |
| Household size | 0.036*** | 0.004 |
| *Income* | | |
| Income <= 40,000 | -0.032*** | 0.009 |
| 80,000>=Income > 40,000 | -0.003 | 0.007 |
| Income >80,000 | omitted | |
| ***Heating degree days*** | | |
| HDD | 0.001*** | 0.0001 |

| | Coefficients | Robust Std. Err |
|---|---|---|
| HDD squared | -9.39e-07 | 7.54e-08 |
| ***Dwelling Characteristics*** | | |
| Programmable thermostat | -0.037*** | 0.011 |
| Attic insulated | -0.025*** | 0.008 |
| *Age of windows* | | |
| Age $\leq$5 years | omitted | |
| 10 years $\geq$Age$>$ 5 years | -0.078 | 0.052 |
| 15 years $\geq$Age$>$ 10 years | 0.011 | 0.04 |
| Age> 15 years | -0.002 | 0.031 |
| Natural gas water heater | 0.025*** | 0.007 |
| Supplemental heating | 0.076*** | 0.012 |
| Garage heated | 0.043*** | 0.013 |
| Basement heated | 0.00009*** | 8.63e-06 |
| Total heating area (excluding garage and basement) | 0.0002*** | 7.51e-06 |
| *Age of heating system* | | |
| Age $\leq$5 years | omitted | |
| 10 years $\geq$Age$>$ 5 years | 0.010 | 0.011 |
| 15 years $\geq$Age$>$ 10 years | 0.039*** | 0.014 |
| 20 years $\geq$Age$>$ 15 years | 0.066*** | 0.012 |
| 25 years $\geq$Age$>$ 20 years | 0.104*** | 0.017 |
| Age >25 years | 0.031*** | 0.009 |
| Year built | -0.0003** | 0.00016 |
| *Housing Type* | | |
| Single Detached | 0.282*** | 0.046 |
| Double | 0.228*** | 0.050 |
| Row and Terrace | 0.141*** | 0.047 |
| Duplex | 0.067 | 0.049 |
| Apartment | omitted | |
| ***Geographic and time fixed effects*** | | |
| CMA | Yes | |
| Year | Yes | |
| Month | Yes | |
| **Number of households** | 4800 | |
| **Number of observations** | 51600 | |
| $\boldsymbol{R^2}$ | 0.69 | |
| **Probability of F- test:** $\varphi_1 = \varphi_2$ | 0.02 | |
| **Probability of F- test:** $\varphi_1 = \varphi_3$ | 0.94 | |

Note: Sampling weights are used in all regressions.*, **, and *** denote significance at the 10%, 5% and 1% levels

In terms of the carbon tax, my results suggest that a one dollar increase in the carbon tax decreases natural gas consumption in brown households by 10.3%. For all other households, I find that the carbon tax has a statistically insignificant effect on natural gas consumption. An F-test is used to test for the salience of the carbon tax for brown households. I find that brown households are more than four times more responsive to the carbon tax than they are to an equivalent change in the market price.

As a robustness check, Table 4.6 reports results from several alternative specifications. Once again, all controls for household and dwelling characteristics, HDD, and geographic and time fixed effects are included in the models, but are not reported directly in the table for the sake of space. All of the models use a semi-log specification. Columns (1) through (5) report the estimated coefficients using variable rates for the price of natural gas and columns (6) through (10) report results using annual fixed rates. Overall, the results of these robustness checks confirm that brown households behave statistically differently from non-brown households in terms of response to the carbon tax. Further, I find that browns are more responsive to the carbon tax than to equivalent changes in the market price of natural gas. Consistent with the baseline specification, all of the alternative specifications indicate that the price impacts on browns and non-browns are not statistically different from each other.

Table 4.6. *Effect of price and carbon tax on natural gas consumption varied by environmental preference*

| | Variable rates | | | | | Annual fixed rate | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1)-baseline | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Price*brown indicator ($\varphi_1$) | -0.024*** (0.004) | -0.025*** (0.003) | -0.018*** (0.004) | -0.030*** (0.004) | -0.023*** (0.004) | -0.049*** (0.011) | -0.032*** (0.011) | -0.0009 (0.010) | -0.020*** (0.008) | -0.048*** (0.011) |
| Carbon tax*brown indicator ($\varphi_2$) | -0.103*** (0.035) | -0.142*** (0.032) | -0.122*** (0.033) | -0.109*** (0.035) | -0.098*** (0.035) | -0.111*** (0.040) | -0.156*** (0.042) | -0.122*** (0.040) | -0.137*** (0.040) | -0.118*** (0.043) |
| Price*non-brown indicator ($\varphi_3$) | -0.025*** (0.005) | -0.024*** (0.004) | -0.019*** (0.005) | -0.028*** (0.005) | -0.024*** (0.004) | -0.051*** (0.006) | -0.038*** (0.006) | -0.0011 (0.005) | -0.021*** (0.005) | -0.052*** (0.006) |
| Carbon tax*non-brown indicator ($\varphi_4$) | 0.020 (0.026) | -0.018 (0.021) | -0.014 (0.021) | 0.016 (0.026) | 0.021 (0.024) | 0.015 (0.030) | -0.052* (0.033) | -0.026 (0.033) | 0.019 (0.033) | 0.023 (0.030) |
| ***Geographic and time fixed effects*** | | | | | | | | | | |
| CMA | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | | Yes |
| Year | Yes | Yes | | Yes | | Yes | Yes | | Yes | |
| Month | Yes | | Yes | Yes | | Yes | | Yes | Yes | |
| Year*month | | | | | Yes | | | | | Yes |
| **Prob of F- test:** $\varphi_1 = \varphi_2$ | 0.02 | 0.01 | 0.00 | 0.08 | 0.07 | 0.10 | 0.01 | 0.00 | 0.01 | 0.09 |
| **Prob of F- test:** $\varphi_1 = \varphi_3$ | 0.94 | 0.89 | 0.66 | 0.73 | 0.92 | 0.63 | 0.44 | 0.28 | 0.74 | 0.46 |

Note: All regressions include the control variables- household characteristics, dwelling characteristics, and HDD. Sampling weights are used in all regressions.*, **, and *** denote significance at the 10%, 5% and 1% levels. Standard errors are in parentheses.

*B. Robustness checks*

<u>Brown, grey, and green households</u>

Table 4.7 reports the results of an additional robustness check, where households are divided into three categories: green, grey, and brown. Households are defined as green if their green index is greater than or equal to 3. Using this cut-off, 34% of households in the sample are classified as green households. Grey households are those with an index value equal to 2. Using this criterion, 32% of the sample is classified as grey. Brown households are those with an index value less than or equal to 1. Approximately 34% of households in the sample are classified as brown.

With respect to price, the overall impact of a one dollar change in the price of natural gas is to reduce demand by 1.9% (1.8%, 1.6%) for green (grey, brown) households. These differences between green, grey and brown households are not statistically significant at conventional significance levels.

The results from this specification suggest that brown households respond to a one dollar increase in the carbon tax by decreasing natural gas consumption by 11.1%. Neither grey nor green households reduce natural gas consumption in response to the carbon tax. As in the baseline specification, I find that brown households are the only households to respond to the carbon tax. When the non-brown households are decomposed into grey and green households neither significantly reduce their natural gas consumption in response to the carbon tax. Therefore, the results from this robustness check are consistent with the baseline specification.

Table 4.7. *Green, Grey and Brown household responses to carbon tax*

| | Variable price - baseline | |
|---|---|---|
| | Estimated Coefficients | Robust Std. Err. |
| Price*green indicator | -0.019*** | 0.004 |
| Price*grey indicator | -0.018*** | 0.005 |
| Price*brown indicator | -0.016*** | 0.005 |
| Carbon tax*green indicator | 0.028 | 0.034 |
| Carbon tax* grey indicator | 0.050 | 0.038 |
| Carbon tax*brown indicator | -0.083*** | 0.035 |
| *Fixed effects* | | |
| CMA | Yes | |
| Year | Yes | |
| Month | Yes | |
| **P value of F- test:** Price *brown indicator= Carbon tax*brown indicator | 0.01 | |

Note: All regressions include the control variables- household characteristics, dwelling characteristics, and HDD. Sampling weights are used in all regressions.*, **, and *** denote significance at the 10%, 5% and 1% levels.

## Decomposition of Environmental Index

The questions used to construct the environmental index capture four actions or behaviours that are associated with pro-environmental attitudes. There is little correlation among these questions; the correlation among these questions tends to be less than 0.3. This suggests, for example, that households purchasing eco-friendly cleaning products may not be the same group of households doing recycling and composting. Pro-environmental behaviour, whether measured by households using their own shopping bags, purchasing eco-friendly cleaning products, doing composting, or recycling, is associated with differential responses to the carbon tax.

As a robustness check I regress the log of natural gas consumption on the price of natural gas, the carbon tax, and interactions between these two variables and each of the environmentalism index questions. The controls used in the previous regressions are also included but are not reported for the sake of space. The estimates are reported in Table 4.8 column (1). In this robustness check “brown” households are those that receive a score of 0 for the environmental ideology index. This is, therefore, a more stringent criterion for a household to be considered "brown" than in the baseline specification. I break the environmental ideology index into the four seperate questions and introduce four new indicator variables, $I_1, I_2, I_3,$ and $I_4$, where the indicator is equal to one if the household always/often uses their own shopping bags, always/often purchases eco-friendly cleaning products, always composts, or always recycles, respectively.

I find that brown households respond to a one dollar carbon tax by decreasing their natural gas consumption by 17.3% (see column (1) in Table 4.8). The results also suggest that brown households respond more to the carbon tax than to equivalent price changes. When each of the four new indicator variables are interacted with the carbon tax, I find that the non-brown households are less responsive to the carbon tax. The exception is those households that compost, who are no more responsive to the carbon tax than brown households.

I also find that the results are generally robust to including each of the environmental indicator variables individually in separate regressions. These estimates are reported in Table 4.8 columns (2) - (5). In response to the carbon tax, households that do not always/often use their own shopping bag (do not always/often purchasing eco-friendly cleaning products, do not always compost, do not always recycle) decrease their natural gas consumption by 14% (6.4%, 5.6%, 5.8%). Households that always/often use their own shopping bag (always/often purchasing eco-friendly cleaning products, always compost, always recycle) behave statistically differently from households not conducting the activities and it appears as though they do not repond to the carbon tax, which is consistent with the results from the baseline specification.

Table 4.8. *Estimates for the effect of price and carbon taxes on natural gas consumption using separated environmentalism index questions - robustness check*

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Price | -0.016*** | -0.023*** | -0.024*** | -0.022*** | -0.021*** |
| | (0.004) | (0.004) | (0.004) | (0.004) | (0.004) |
| Price*$I_1$ | 0.0002 | -0.002 | | | |
| | (0.002) | (0.002) | | | |
| Price*$I_2$ | -0.003 | | 0.003 | | |
| | (0.002) | | (0.002) | | |
| Price*$I_3$ | -0.002 | | | -0.001 | |
| | (0.002) | | | (0.002) | |
| Price*$I_4$ | -0.01*** | | | | -0.01*** |
| | (0.002) | | | | (0.002) |
| Carbon tax | -0.173*** | -0.140*** | -0.064*** | -0.056*** | -0.058*** |
| | (0.048) | (0.027) | (0.025) | (0.027) | (0.024) |
| Carbon tax *$I_1$ | 0.138*** | 0.143*** | | | |
| | (0.041) | (0.043) | | | |
| Carbon tax *$I_2$ | 0.058* | | 0.072*** | | |
| | (0.031) | | (0.032) | | |
| Carbon tax *$I_3$ | 0.023 | | | 0.055* | |
| | (0.028) | | | (0.030) | |
| Carbon tax *$I_4$ | 0.063*** | | | | 0.078** |
| | (0.025) | | | | (0.026) |
| P value of F- test: price=carbon tax | 0.008 | 0.03 | 0.09 | 0.18 | 0.13 |

Note: All regressions include control variables (household characteristics, dwelling characteristics, HDD, CMA, year and month fixed effects) listed in Table 4. $I_1$-$I_4$ are dummy variables representing for green index questions with $I_1(I_2, I_3, I_4)$=1 indicating households always/often using their own shopping bag (always/often purchasing eco-friendly cleaning products, always do composting, always do recycling). *, **, and *** denote significance at the 10%, 5% and 1% levels. Standard errors are in parentheses.

*Alternative environmentalism index measure*

I conduct a final robustness check. The following question appears in the 2011 HES: "In the past 12 months, did you engage, without pay, in activities aimed at conservation or protection of the environment or wildlife?" This question can be used as an indicator reflecting one feature of environmentalism: the importance of nature to the survey respondent. Unfortunately, this question does not appear in the 2007 HES. As a robustness check, I estimate the models using the 2011 data only and use this question as the environmental indicator. In Table 4.9, I report the results of this regression. I once again find that brown households respond to the carbon tax: a one dollar increase in the carbon tax decreases natural gas consumption by 6.7% which is smaller than the baseline specification. I also find that other households do not respond to the carbon tax, though they are not statistically different from browns. Similar to the previous salience results, the results suggest that the carbon tax is more salient than equivalent price changes for the brown households.

Table 4.9. *Alternative environmentalism index measure*

| | Variable price - baseline | |
|---|---|---|
| | Estimated Coefficients | Robust Std. Err. |
| Price | -0.008** | 0.003 |
| Price*$I_5$ | -0.002 | 0.004 |
| Carbon tax | -0.067** | 0.038 |
| Carbon tax*$I_5$ | 0.031 | 0.033 |
| *Fixed effects* | | |
| CMA | Yes | |
| Month | Yes | |
| P value of F- test: Price=Carbon tax | 0.09 | |

Note: The regression includes control variables - household characteristics, dwelling characteristics, HDD. $I_5$ is dummy variable representing for the question about the importance of nature with $I_5$ =1 indicating households engaged in activities aimed at conservation or protection of the environment. *, **, and *** denote significance at the 10%, 5% and 1% levels.

*Differences-in-differences-in-differences estimates*

Another alternative approach to investigate whether brown households behave differently from other households in response to the carbon tax is to construct a "triple difference" (DDD) estimate of the effect of the intervention. I estimate the following model:

$$\log(q_{ht}) = \beta_0 + \beta_1 p_{ht} + \beta_2 I_{bh} + \beta_3 Year + \beta_4 BC + \beta_5(Year * I_{bh}) + \beta_6(BC * I_{bh}) + \beta_7(BC * Year) + \beta_8(BC * Year * I_{bh}) + \boldsymbol{X}_{ht}\theta + \mu_{ht} \quad (27)$$

where $Year * I_{bh}$, $BC * I_{bh}$, $BC * Year$ and $BC * Year * I_{bh}$ are interaction terms; $\beta_i$ and θ are the related coefficients, $i = 1, \ldots, 8$; and $u_{ht}$ is the error term.

In the DDD method, the third-level interaction, $\beta_8$, is the coefficient of interest. If $\beta_8$ is negative and statistically significant, then we can conclude that brown households in BC reduced their natural gas consumption after the carbon tax policy relative to non-brown households. The DDD approach yields results similar to those in the tax salience model. Table 4.10 reports the estimates using the DDD method.

Table 4.10. *Estimates of difference in difference in difference model*

| | Variable rates - baseline | |
|---|---|---|
| | Estimated Coefficients | Robust Std. Err. |
| Price ($\beta_1$) | -0.019*** | 0.002 |
| BC ($\beta_4$) | -0.016 | 0.011 |
| Year ($\beta_3$) | -0.072*** | 0.012 |
| Brown indicator ($\beta_2$) | 0.032*** | 0.009 |
| BC*Year ($\beta_7$) | 0.054* | 0.031 |
| BC*Brown indicator ($\beta_6$) | 0.039* | 0.023 |
| Year* Brown indicator ($\beta_5$) | -0.144*** | 0.017 |
| BC*Year*Brown indicator ($\beta_8$) | -0.114** | 0.059 |

Note: The regression includes control variables - household characteristics, dwelling characteristics, HDD. *, **, and *** denote significance at the 10%, 5% and 1% levels

The point estimate of $\beta_8$ is equal to -0.114, which suggests that brown households in BC reduce natural gas consumption relative to non-brown households in response to the carbon tax. Further, I calculate the impact of the carbon tax on brown households' natural gas consumption. The estimated impact is -0.060.[66] This implies that the brown households reduce their natural gas consumption by 6% in response to the carbon tax, with a *p*-value of 0.09. From 2007 to 2011, the carbon tax increased gradually from 0 to \$1.12/GJ. Therefore, when converted into a marginal impact, my results suggest a \$1/GJ carbon tax decreases natural gas consumption by 5.36% for brown households. Note that in the baseline specification of the tax salience model a \$1/GJ increase in the carbon tax decreases natural gas consumption by 10.3% for brown households. Although both the tax salience model and the DDD model imply a reduction of natural gas consumption in response to the carbon tax for brown households, the estimated impact of the carbon tax on brown households' natural gas consumption using a DDD approach is roughly half that of the tax salience model.

[66] It is equal to $\beta_7 + \beta_8$

Based on the results from the DDD approach, one can calculate the overall impact of the carbon tax on BC households' natural gas consumption. I find the overall impact is statistically insignificant. When the carbon tax increases from 0 to \$1.20/GJ, household natural gas consumption in BC decreases by 1.5%. However, this impact is statistically insignificant (with a *p*-value equal to 0.588).[67]

Further, the estimates in DDD approach allow one to discover the pre-policy/post-policy consumption of natural gas for brown households' relative to non-brown households.[68] According to the estimation above, during the pre-policy period, I find that brown households consume more natural gas in both BC ($\beta_2 + \beta_6 = 0.071$) and in all six provinces ($\beta_2 + \beta_6 * \overline{BC} = 0.038$) than non-brown households. Regarding the post-policy period consumption, I do not find any evidence showing brown households natural gas consumption in BC is significantly different from the non-brown households in BC ($\beta_2 + \beta_5 + \beta_6 + \beta_8 = -0.169$, which is statistically insignificant with a *p*-value of 0.284). The carbon tax has therefore appeared to equalize natural gas consumption across brown and non-brown households in BC.

## 4.5. Conclusion

In this chapter, I estimate how household natural gas consumption responds to the BC carbon tax. My empirical results have several important implications. First, I find little evidence that the carbon tax is more salient than equivalent price changes using overall sample. Second, my results suggest that the impact of the carbon tax is more effective for brown households than for other households. I find that for brown households, the carbon tax is more salient than

[67] It is equal to $\beta_7 + \beta_8 * \overline{I_{bh}}$

[68] The estimated coefficients $\beta_2 + \beta_6$ provide the marginal effect of the type of households varied by environmental ideology on natural gas consumption during the pre-policy in BC. The estimated coefficients $\beta_2 + \beta_6 * \overline{BC}$ provide the marginal effect of the type of households on natural gas consumption during the pre-policy over all six provinces in Canada; the estimated coefficients $\beta_2 + \beta_5 + \beta_6 + \beta_8$ provide the marginal effect of the type of households on natural gas consumption during the post-policy in BC. The estimated coefficients $\beta_2 + \beta_5 + \beta_6 * \overline{BC} + \beta_8 * \overline{BC}$ provide the marginal effect of the type of households on natural gas consumption during the post-policy over all six provinces in Canada.

equivalent market price changes. I also find that non-brown households do not respond to the carbon tax.

This research examines household responses to a mandatory constraint on consumption. I find that brown households are more responsive to the mandatory constraint than non-brown households. Costa and Kahn (2013) find a non-price “nudge” is more effective for political liberal/environmentalist households while it has the unintended impact of increasing consumption in politically conservative households. While “nudges” may be effective for those households responsive to the message, carbon pricing appears to work best for households that will take steps to reduce their tax bills. Further, it may be the case that some households engage in voluntary restraint prior to the carbon tax and have little room to decrease natural gas consumption in response to a carbon tax. This is consistent with my result. I find that non-brown households respond very little to the carbon tax while brown households do respond to the carbon tax by reducing consumption.

My results provide some guidance for policy makers. There is no "one-size-fits-all" strategy in household energy conservation. If this is the case, then policy makers need to design and implement different policies for different households. Based on this research, reducing household GHG emissions may be best achieved with a combination of a mandatory carbon tax, which is more effective for brown households, complemented with voluntary "nudges," which may be more effective in reducing energy consumption by non-brown households.

**REFERENCES**


Brounen, D., N. Kok, and J.M. Quigley. 2012. Residential Energy Use and Conservation: Economics and Demographics. *European Economic Review* 56: 931-945.

Chetty, R., A. Looney, and K. Kroft. 2009. Salience and Taxation: Theory and Evidence. *American Economic Review* 99(4): 1145-1177.

Clark, C.F., M.J. Kotchen, and M.R. Moore. 2003. Internal and external influences on pro-environmental behaviour: participation in a green electricity program. *J. Environ. Psych.* 23:237–246.

Costa, D., and M. Kahn. 2010. Why has California's electricity consumption been so flat since the 1980s? A microeconometric approach. NBER Working Paper 15978. Retrieved from http://www.nber.org/papers/w15978.pdf (accessed 11.01.2014)

Costa, D., and M. Kahn. 2013. Energy Conservation "Nudges" and Environmentalist Ideology: Evidence from a Randomized Residential Electricity Field Experiment. *Journal of the European Economic Association* 11(3): 680-702.

Davis, L., and L. Kilian. 2011. The Allocative Cost of Price Ceilings in the U.S. Residential Market for Natural Gas. *Journal of Political Economy* vol. 119(2), pages 212 - 241.

Dubin, J., and D. McFadden. 1984. An Econometric Analysis of Residential Electric Appliance Holdings and Consumption. *Econometrica* 52: 345–362.

Elgie, S., and J. McClay. 2013. Policy Commentary: BC's Carbon Tax Shift is Working Well after Four Years. *Canadian Public Policy* 39(2): 1-10.

Energyshop. Deregulated Natural Gas Prices. http://www.energyshop.com/es/prices/MB/gasMB.cfm?ldc_id=7 (accessed 5.23.2014)

Finkelstein, A. 2009. E-Ztax: Tax Salience and Tax Rates. *Quarterly Journal of Economics*. 124(3): 969-1010

Fritzsche, D. J. 1981. An analysis of energy consumption patterns by stage of family life cycle. *Journal of Marketing Research* 18 (2), 227–232.

Forest Stewardship Council (FSC). 2013. A mainstream concern: FSC Global Consumer Research Highlights. http://ic.fsc.org/force-download.php?file_connector=2811 (accessed 5.23.2014)

Gallagher,K., and E. Muehlegger. 2011. Giving Green to Get Green? Incentives and Consumer Adoption of Hybrid Vehicle Technology. *Journal of Environmental Economics and Management* 61: 1-15.

Global News. 2014. Surging natural gas prices hitting home for Canadians. http://globalnews.ca/news/1191671/surging-natural-gas-prices-hitting-home-for-canadians

Kahn, M. E. 2007. Do Greens Drive Hummers or Hybrids? Environmental Ideology as a Determinant of Consumer Choice. *Journal of Environmental Economics and Management* 54:129-145.

Kahn, M. E. & E. A. Morris. 2009. Walking the walk: New tests of environmentalism's association with green travel behaviour. *Journal of the American Planning Association*, 75(4), 389-405.

Kotchen, M. J. and M. R. Moore. 2007. Private Provision of Environmental Public Goods: Household Participation in Green-Electricity Programs. *Journal of Environmental Economics and Management* 53, 1–16.

Kotchen, M. J. and M. R. Moore. 2008. Conservation: From Voluntary Restraint to a Voluntary Price Premium. *Environmental and Resource Economics* 40, 195–215.

Li, S., Linn, J., and E. J. Muehlegger. 2014. Gasoline Taxes and Consumer Behaviour. *American Economic Journal: Economic Policy*, 6(4):1-43, 2014.

Marion, J. & E. Muehlegger. 2011. Fuel tax incidence and supply conditions. *Journal of Public Economics.* vol. 95(9), pages 1202-12

Mansur, E.T., R. Mendelsohn, and W. Morrison. 2008. Climate Change Adaptation: A Study of Fuel Choice and Consumption in the US Energy Sector. *Journal of Environmental Economics and Management* 55 (2): 175–193.

National Energy Board. Canadian Energy Pricing Trends 2000-2010 - Energy Facts. Retrieved from http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/prcng/cndnnrgprcngtrndfct2011/cndnnrgprcngtrndfct-eng.html

Natural Resources Canada. ARCHIVED - ecoENERGY Retrofit – Homes Program. Retrieved from http://www.nrcan.gc.ca/energy/efficiency/housing/home-improvements/5003

National Resource Canada. Frequently Asked Questions About Natural Gas Prices. Retrieved from https://www.nrcan.gc.ca/energy/natural-gas/5685#faq11

National Resource Canada. ARCHIVED - ecoENERGY Retrofit – Homes Program. http://www.nrcan.gc.ca/energy/efficiency/housing/home-improvements/5003 (accessed 5.23.2014)

O'Neill, B. C., and B. S. Chen. 2002. Demographic determinants of household energy use in the United States. *Population and Development Review* 28, 53–88.

Pettit, D., and J. P. Sheppard.1992. It's Not Easy Being Green: The Limits of Green Consumerism in Light of the Logic of Collective Action. *Queens Quarterly* 99 (3): 328-350.

Rhodes, E., and M. Jaccard. 2013. A Tale of Two Climate Policies: Political Economy of British Columbia's Carbon Tax and Clean Electricity Standard. *Canadian Public Policy* 39(2): 37-51.

Rivers, N., and B. Schaufele. 2012. Carbon Tax Salience and Gasoline Demand. Working Paper #1211E, Ottawa, ON: Graduate School of Public and International Affairs and Institute of the Environment, University of Ottawa.

Ryan, D., and N.A. Razek. 2012. Background Report: The Likely Effect of Carbon Pricing on Energy Consumption in Canada. Sustainable Prosperity Report. 2012 (May).

Statistics Canada. CANSIM table: 1290003. Sales of natural gas-monthly

Statistics Canada. 2008. Greenhouse gas emissions–a focus on Canadian households. http://www.statcan.gc.ca/pub/16-002-x/2008004/article/10749-eng.htm

**CHAPTER 5**

## Summary and Conclusions

The purpose of this dissertation is to empirically estimate the impact of behaviour altering taxes on household consumption. The dissertation consists of three essays. The first essay conducts an empirical examination of the impact of a hypothetical "fat tax" on household food consumption in Canada from both health and economic perspectives. Using aggregate data, the second essay tries to identify the impact of the BC carbon tax on residential natural gas consumption using a newly developed statistical data driven method—the synthetic control approach. As a further investigation of the BC carbon tax, the third essay examines the heterogeneous response to the carbon tax varied by environmental ideology. Further, the salience of the carbon tax on natural gas consumption is assessed relative to an equivalent price change.

The results of the first essay indicate that a fat tax with a lump-sum transfer to households is the preferred tax reform when compared to a stand- alone fat tax, a stand- alone subsidy on fruits and vegetables, and a fat tax with the collected revenue used to subsidise fruits and vegetables. The fat tax with a lump sum transfer benefits low income households (with a positive progressivity index) and lowers total household caloric intake. This result provides some policy implications. More attention is being given to controlling obesity through government policy. This research demonstrates that a stand- alone fat tax without recycling the collected revenue is the most regressive policy. In terms of other food policy reforms, a stand- alone subsidy is a progressive strategy but it increases government expenditures and increases households' caloric intake. A fat tax with recycled revenue subsidising fruits and vegetables does not achieve substantial decreases in energy intake. In addition, it is slightly regressive. Therefore, the most effective policy is to use the recycled tax revenue to support a lump-sum transfer to households. On the one hand, this is a progressive policy that benefits the poor, and on the other hand, it decreases household energy intake. When policy makers consider applying a food policy that encourages households to adopt a healthy diet, my results suggest a lump-sum transfer of the collected fat tax revenue is unarguably the most effective from both health and economic perspectives.

By investigating the impact of the BC carbon tax, the second and the third essays shed light on the effectiveness of the tax on residential natural gas consumption. Further, an investigation of a heterogeneous response to the carbon tax varied by household environmental ideology demonstrates that less environmentally conscious households reduce their natural gas consumption in response to the carbon tax. In contrast, the more environmentally conscious households do not respond to the carbon tax.

In the second essay, I find little evidence that the BC carbon tax does not significantly decrease per capita residential natural consumption. In contrast to the results from BC government's 2012 report, where BC's 2010 total natural gas consumption declines from its 2007 level more than the rest of Canada, no prominent decline in per capita residential natural gas consumption in BC is discovered in my study. In fact, the estimated result in the second essay is not comparable to the government report. In my second essay, residential natural gas consumption is targeted, whereas the BC government report focuses on a broader range of natural gas consumption including usage in transportation, commercial, and agriculture. It is quite possible the reduction of total natural gas consumption is driven by decreasing consumption used in the commercial or transportation sector, instead of residential usage. However, the BC carbon tax policy is just five years old, and further study is needed to discover its long- run impact, and reach firm conclusions about its exact environmental and economic effects regarding natural gas consumption.

The results in the third essay provide some policy implications. When households are distinguished on the basis of environmental ideology, the less environmentally conscious households respond to the carbon tax by reducing natural gas consumption. The more environmentally conscious households do not respond to the carbon tax. The prior research examining the impact of voluntary "nudges" on residential energy use, discovers that the success of a nudge hinges in part on environmental ideology. The prior research finds that a "nudge" may effectively change household energy conservation behaviour for environmentally conscious households. For less environmentally conscious households, government policy makers might consider using mandatory constraints, such as a carbon tax to reduce residential energy consumption. Therefore, my results show that the carbon tax might be successfully used to complement voluntary "nudges," since it appears that mandatory and voluntary policy tools influence different types of households.