# CONSUMERS' DECISIONS ON CALORIES, FAT, AND CARBOHYDRATES WITH RESPECT TO FOOD PRICES AND EXPENDITURES

by

Qin Xu

Submitted in partial fulfilment of the requirements
for the degree of Master of Arts

at

Dalhousie University
Halifax, Nova Scotia
December 2011

DALHOUSIE UNIVERSITY

DEPARTMENT OF ECONOMICS

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "CONSUMERS' DECISIONS ON CALORIES, FAT, AND CARBOHYDRATES WITH RESPECT TO FOOD PRICES AND EXPENDITURES" by Qin Xu in partial fulfilment of the requirements for the degree of Master of Arts.

Dated: December 6, 2011

Supervisor: _________________________________

Readers: _________________________________

_________________________________

DALHOUSIE UNIVERSITY

DATE: December 6, 2011

AUTHOR: Qin Xu

TITLE: CONSUMERS' DECISIONS ON CALORIES, FAT, AND CARBOHYDRATES WITH RESPECT TO FOOD PRICES AND EXPENDITURES

DEPARTMENT OR SCHOOL: Department of Economics

DEGREE: MA CONVOCATION: May YEAR: 2012



Signature of Author

DEDICATION PAGE

**To my dear mom – Liangzhen Xu and dad – Yong Xu**

**To my friends Zhenyi, Yunfei, Yumei, Jing, and Qiumei**

**Thanks for your support and encouragement!**

.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# ABSTRACT

Obesity is a big health issue in the developed world, especially in the US. This has led to a call to implement policies to control obesity. The major materials thought to contribute to obesity are calories, fat, and carbohydrates. In previous research, consumer's reactions to these materials have been studied separately. However, these three materials have different adverse effects in the process of metabolism. Therefore, it is important to study these three materials simultaneously to in order to develop effective policies to control obesity. This study uses the Theil/Nelson model of characteristics to develop a set of food price and expenditure elasticities for three materials: calories, fat and carbohydrates. Some results include: 1) Consumption decision on calories, fat, and carbohydrates to food prices and expenditures are different, so studying obesogenic materials simultaneously is essential. 2) A composite commodity tax on fats and oils is effective for the US total population, but might not be effective for the poor population.

## LIST OF ABBREVIATIONS AND SYMBOLS USED

| | |
|---|---|
| AIDS | Almost Ideal Demand System |
| $AP$ | aggregated price for all items |
| $\boldsymbol{B}$ | an $M \times 1$ vector of $\boldsymbol{B}_G$ |
| $\boldsymbol{B}_G$ | an $N \times 1$ vector of parameters in a composite good for years |
| $\widehat{\mathbf{B}}$ | an $MN \times 1$ vector of the parameters estimations |
| BLS | Bureau of Labor Statistics |
| BMI | Body Mass Index |
| $C_G$ | the composite characteristic of carbohydrates in $G$ |
| CCT | Composite Commodity Theorem |
| CNPP | Center for Nutrition Policy and Promotion |
| CPI | Consumer Price Index |
| $E_G$ | expenditure in composite commodity $G$ |
| $F_G$ | the composite characteristic of fat in $G$ |
| $FE$ | nominal food expenditure |
| $G$ | a composite commodity, numbered from 1 to $M$ (The Same as $H$) |
| GADS | Generalized Addilog Demand System |
| GCCT | Generalized Composite Commodity Theorem |
| GLS | Generalized Least Square Regression |
| $H$ | a composite commodity, numbered from 1 to $M$ (The Same as $G$) |
| $I$ | real food expenditure (we also regard it as income) |
| $i$ | a elementary good in a composite commodity $G$ |
| $j$ | the $j$-th quality characteristic |
| IAIDS | Inverse Almost Ideal Demand System |
| $\boldsymbol{K}$ | an $M \times 1$ vector of $\boldsymbol{K}_G$ |
| $\boldsymbol{K}_G$ | an $N \times 1$ vector of calories consumption in a composite good for years |
| $K_G$ | the composite characteristic of calories in $G$ |
| k | the amount of quality characteristics |
| kcal | kilocalorie |
| $M$ | the number of composite commodity groups |
| $\boldsymbol{N}$ | the matrix of nutrient content per unit of food |
| $O_G$ | the other composite quality characteristics in $G$ |
| OLS | Ordinary Least Square |
| $P$ | the vector of $P_G$'s |
| $P_G$ | composite commodity price |
| $p_G$ | the composite price that corresponding to composite quality |
| $P_{Ht}$ | food price of one composite commodity in the time of $t$ |
| $p_i$ | price of elementary good $x_i$ |

| | |
|---|---|
| $p_i$* | the "base" price of good $x_i$ |
| PIGL | Price Independent Generalized Linear |
| POGLOG | Price Independent Generalized Logarithmic |
| $Q_G$ | composite commodity quantities |
| $\boldsymbol{q}$ | the vector of food quantities |
| $q_G$ | consumed physical quantity of composite commodity $G$ |
| SUR | Seemingly Unrelated Regression |
| U | Utility |
| $\boldsymbol{u}$ | an $M \times 1$ vector of $\boldsymbol{u}_G$ |
| $\boldsymbol{u}_G$ | an $N \times 1$ vector of random disturbances in a composite good for years |
| US | United States |
| $V_G$ | unit values in composite commodity G |
| $v_G$ | the quality of composite commodity $G$ |
| $\boldsymbol{X}$ | an $M \times M$ matrix of $\boldsymbol{X}_G$ |
| $\boldsymbol{X}_G$ | an $N \times (2 + M)$ matrix of regressors in a composite good for years |
| $\overline{\boldsymbol{X}}$ | the identical regressors |
| $x_i$ | consumed quantity of elementary good $i$ |
| Y | household income |
| $y_{Gt}$ | expenditure or consumption of calories, fat, and carbohydrates in $G$ for years |
| $\boldsymbol{z}$ | the vector of nutrients in foods |
| $\beta_x$ | income elasticity of a variable $x$ |
| $\theta_x$ | price elasticity of a variable $x$ |
| $\boldsymbol{\Sigma}$ | an $M \times M$ variance-covariance matrix for one observation |
| $\boldsymbol{\Omega}$ | an $MN \times MN$ overall variance-covariance matrix |

# ACKNOWLEDGEMENTS

I would like to thank my committee members, Drs. Kuan Xu and Courtney Ward, and especially my supervisor Dr. J. Stephen Clark for their guidance, expertise, and patience through the whole research project. I also would like to thank Bureau of Labor Statistics (BLS) and Center for Nutrition Policy and Promotion (CNPP) for providing the data in this project.

# CHAPTER 1 INTRODUCTION

## 1.1 OBESITY

Nowadays, obesity is a major health issue all over the world, especially in the developed world. The prevalence of obesity has brought about lots of concerns, because of the social and health consequences result from problems of obesity. The Body Mass Index (BMI) is a measurement of body weight (World Health Organization, 2011). If a person's BMI is greater than 30, then he is said to be obese, which is an excessive fat accumulation (World Health Organization, 2011).

### 1.1.1 The Prevalence of Obesity

With the improvement in living standards in the US, more food consumption and less physical work result in more obese people. Figure 1 shows the prevalence of obesity among the adults aged 20-74 from 1960 to 2008 in the US.

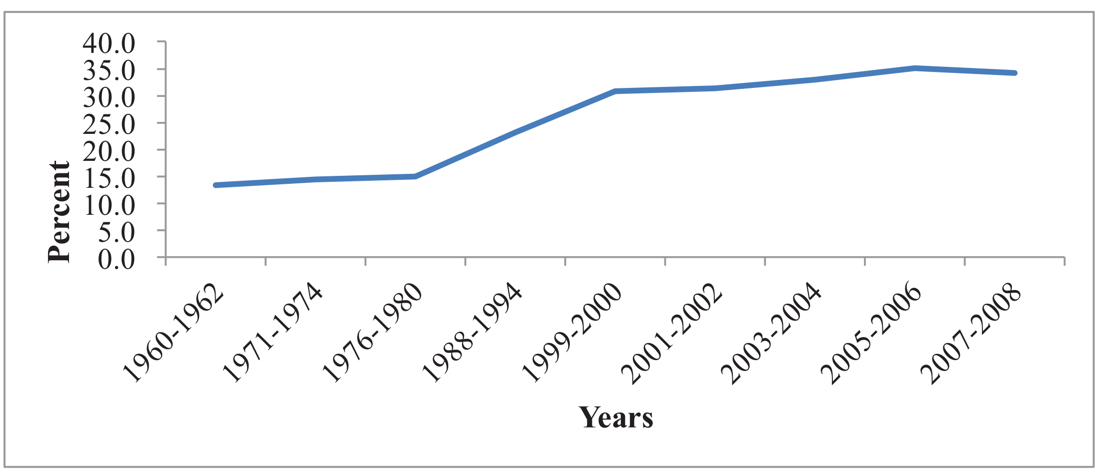


Figure 1 The prevalence of obesity among US adults aged 20-74 from 1960 to 2008. (Data Source: Centers for Disease Control and Prevention, 2010)

Figure 1 demonstrates that the prevalence of obesity among the adults aged 20 – 74 rises 20.9% from 1960 to 2008 in the US. The population of obesity in the US was only 13.4% during the period from 1960 to 1962. However, the population of obesity in the US has exceeded 30% since 1999. According to Figure 1, one-third of the US population was obese in recent years, which implies a serious health issue.

### 1.1.2 The Social and Health Problems of Obesity

Such a high prevalence of obesity has drawn people's attention. They worry about this phenomenon because obesity would lead to some social and health problems. With respect to the first problems, many obese people have problems of poor self-image and low confidence because pursuing slimness is a fashion (Bender, 2008). Difficulty of buying clothes and ridicule might let them feel alone and withdraw from society (Bender, 2008).

Besides the social problems, obese people also face higher health risks than others. Obesity is related to increased morbidity, like lower bone mineral density, varicose veins, hemorrhoids, and arthritis of the hips and knees (Bender, 2008). Obesity is also associated with a higher risk of premature death from a variety of causes, such as cancer, atherosclerosis, coronary heart disease, high blood pressure, stroke, type II diabetes mellitus, and respiratory diseases (Bender, 2008). Bender (2008) shows that obese people have higher risk of death during surgery and postoperative complications. The reasons include longer surgery, harder induction of anesthesia, and impaired lung function due to anesthesia. As a result of adipose tissue in the upper-body segment, obese people also have impaired lung functions (Bender, 2008). Total lung capacity is about only 60 percent of that in lean people (Bender, 2008). Due to impaired lung functions, obese people have higher risk of respiratory distress, pneumonia, and bronchitis (Bender, 2008).

## 1.2 Obesogenic Material Intakes

This section introduces how calories, fat, and carbohydrates contribute to obesity respectively, and what specific roles these three obesogenic materials play in the process of metabolism. Two conceptions need to be clarified: intake and consumption. Intake means the amount of a material that consumers eat. However, consumption means how much a material that consumers purchase from markets. In real life, it is very hard to obtain the data of material intake due to food spoilage, waste, and others, so people talk about intake in the field of metabolism, but substitute consumption for intake in the field of economics.

### 1.2.1 Obesogenic materials

The major dietary factors contribute to obesity are calorie, fat, and carbohydrate (Bender, 2008). In this research, we call them obesogenic materials. To know these three obesogenic materials, first of all, let us start the definition of a calorie.

A calorie, the unit of heat, which means the amount of heat required to increase the temperature of 1 gram (g) of water by $1°C$ (Bender, 2008). In biological systems, kilocalorie (kcal) is used. The conversion formula of kilocalorie is

$$1 \text{ kilocalorie} = 1000 \text{ calories.} \tag{1}$$

That is, a kilocalorie is the amount of heat required to increase the temperature of 1 kilogram (kg) of water by 1°C. From the perspective of food consumption and nutrients, calorie (or kilocalorie) is a measure of total energy from food, which is called metabolic energy. There are four nutrients from diet (i.e. metabolic fuels) that could contribute to metabolic energy: carbohydrates, fat, protein, and alcohol (Bender, 2008). Table 1 presents their energy yield.

Table 1 The energy yield of metabolic fuels. (Data Source: Bender, 2008)

| **Metabolic Fuels** | **Energy (kcal/g)** |
|---|---|
| Fat | 9 |
| Carbohydrates | 4 |
| Protein | 4 |
| Alcohol | 7 |

Table 1 shows that fat contributes 9 kcal per gram, which is the highest energy yield. Alcohol contributes 7 kcal per gram, which ranks the second. Carbohydrates and protein contribute the same amount of energy, which is only 4 kcal per gram.

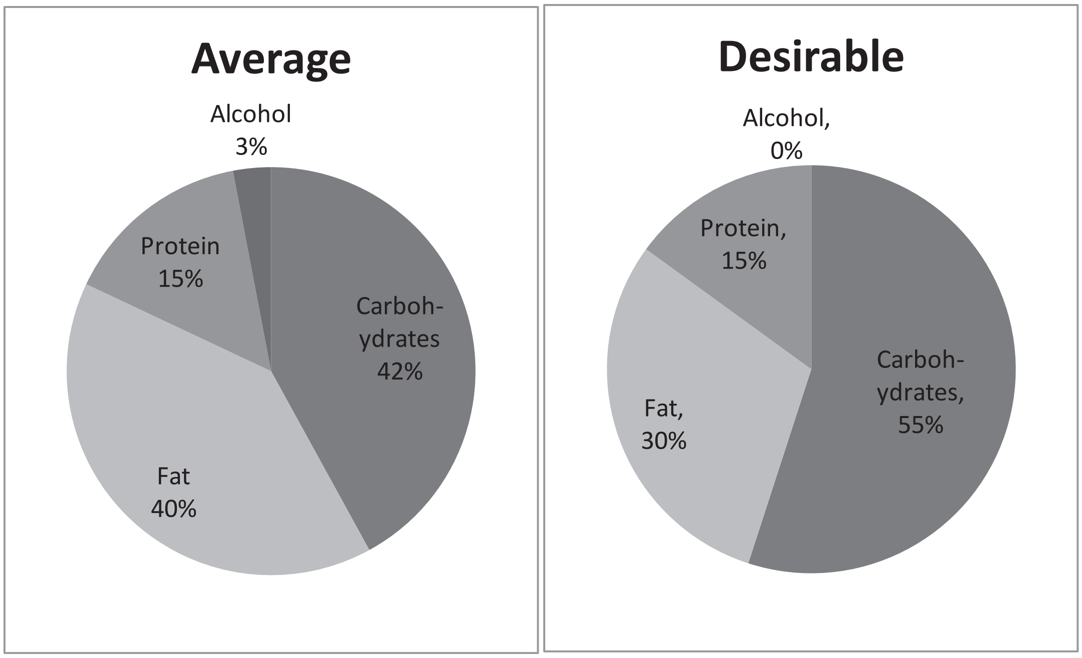


Figure 2 Average and desirable percentage of energy intake from different metabolic fuels. (Data Source: Bender, 2008)

Figure 2 shows the average and desirable percentage of energy intake from those four metabolic fuels. According to Figure 2, we find that the energy intake from fat and carbohydrates has a large proportion, and is approximately 85%. So, fat and carbohydrates are regarded as major obesogenic nutrients. Although Table 1 tells us that alcohol provides the high-energy yield, the percentage of energy intake from alcohol is so small that we can ignore its effect on body weight. Protein also has a small proportion of energy intake. Moreover, its energy yield is low. Therefore, the effect of protein on body weight is secondary to fat and carbohydrates. For these reasons, we treat fat and carbohydrates as major obesogenic nutrients, and ignore the effect of alcohol and protein.

Therefore, fat and carbohydrates are the major obesogenic nutrients contribute to total calories consumed. According to the above introduction, it seems that the definitions of calories, fat, and carbohydrates are not parallel, because calories are major in forms of fat and carbohydrates. However, when consumers purchase food, the roles of calories, fat, and carbohydrates are parallel, because of their different adverse effect (see Section 1.2.3) and the complex way of transformation among them. For example, if the supply of calories exceeds body demand, calories provide energy to help the body functioning properly first, then transfer into fat and store in the body. When people consume fats, it will store in the body first, and then transfers into calories when the body needs more energy (TeensHealth, 2009). Another example is the transformation between fat and carbohydrates. When carbohydrates are too much, carbohydrates will transfer into fat. Nevertheless, when carbohydrates are not enough, fat will transfer into carbohydrates. So, the conceptions of calories, fat, and carbohydrates in this thesis are regarded as parallel. Furthermore, calorie is not nutrient, so we call calories, fat, and carbohydrates "obesogenic materials" rather than "obesogenic nutrients".

### 1.2.2 Energy Intake and Energy Expenditure

In metabolism, no matter what the starting materials are, they would convert to the same end products - carbon dioxide and water. Thus, the total energy yield from these four metabolic fuels is energy intake. People not only need to take energy, but also need to expand energy to maintain the body's functions. Other than maintaining the body's functions, people also expand energy to do physical and mental work. At the end, the amount of energy contributes to obesity is called net energy. The relationship among energy intake, energy expenditure, and net energy is

$$\text{net energy} = \text{energy intake} - \text{energy expenditure}. \tag{2}$$

In real life, consuming food is energy intake, and doing exercise is energy expenditure. Therefore, body weight is affected by both food consumption and exercise. However, in our research, we only focus on obesogenic materials intake, namely energy intake (see Section 2.1 for explanation).

### 1.2.3 Different Adverse Effects

From the above, we know that, calories could cause obesity if there is over intake. However, besides obesity, over intake of calories does not tell us any other harmful effects, because it is only a measurement of energy.

In terms of fat, taking either too little or too much fat is harmful to health. On one hand, fat intake is essential, because a very low-fat diet does not contain enough energy and vitamins A, D, E, and K (Bender, 2008). In addition, moderate amounts of fat provide better taste and flavor (Bender, 2008). On the other hand, over intake of fat might lead to the problems of obesity, chronic diseases, heart disease, cancers, and other health problems (Bender, 2008). It is reported that, if the energy provided from fat is more than 30%, the risks of heart disease and some cancers would become higher (Bender, 2008).

Besides the total intake of fat, different types of fat also affect the health condition differently (Bender, 2008). For example, saturated fatty acids are not good substrates for cholesterol esterification in cell (Bender, 2008), so high-cholesterol patients would buy relatively low saturated fat foods. Unsaturated fatty acids are generally better than saturated fatty acids, like monounsaturated fatty acids. However, trans fatty acid, one of the unsaturated fatty acids, is not good for health, and has been strictly controlled. Therefore, the health condition is affected by different types of fat intake.

The third obesogenic material, carbohydrate, is another main metabolic fuel. Sugar is an important source of carbohydrate, and it is the element in carbohydrates, which contributes most in increasing body weight. It also contributes to many health problems if there is an excessive intake. The harmful effects of over intake of sugars include dental decay, obesity, diabetes mellitus, atherosclerosis and coronary heart disease, and so on (Bender, 2008).

To sum up, calories, fat, and carbohydrates play different roles in the process of metabolism and food consumption. In addition, controlling obesogenic material consumption is essential for the maintenance of good health.

### 1.2.4 Different Contents in Different Foods

In different food categories, the obesogenic material contents are different. Take the nutrient of fat as an example, in the sugar and sweets food category, fat supply percentage per capita per day is 0%, but it is approximately 55% in the fats and oils food category (Center for Nutrition Policy and Promotion, 1984-2006). In contrast, for carbohydrates, its supply in the sugar and sweets is around 37% (Center for Nutrition Policy and Promotion, 1984-2006). However, carbohydrates supply in the fats and oils is 0% (Center for Nutrition Policy and Promotion, 1984-2006). Therefore, adjusting the consumption of different types of food is helpful to control the obesogenic material consumption.

## 1.3 Obesogenic Material Consumption and the Change of Food Prices and Expenditures

From the above, we understand how calories, fat, and carbohydrates contribute to obesity respectively, and these three major obesogenic materials play different roles in the process of metabolism and food consumption. However, how do these obesogenic materials related to food prices and expenditures? In the previous research, consumers' decisions on obesogenic materials to food prices and expenditures have been studies separately. Nevertheless, are consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures different, or the same? Do the relationships lead to the same or opposite direction with respect to a composite commodity tax? And, do the relationships bring about some problems in terms of different food expenditures level populations? Given these questions, we should estimate consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures simultaneously.

In order to explain the relationship between obesogenic materials consumption decision and food prices as well as food expenditures, we take calories as an example. As one food price increases, if calories consumption increases, we call this food "low quality" food. In contrast, if there is lower calories consumption when one food price increases, we call this "high quality" food. The same applies to the other obesogenic materials with respect to the change of food prices. Defining "low quality" and "high quality" foods helps us proposing some policy actions to control obesogenic materials consumption. For instance, imposing a composite good tax on "high quality" food is effective for reducing obesogenic materials consumption. However, imposing a composite good tax on "low quality" food will lead to the opposite direction, so it is not recommended.

Putnam and Allshouse (1999) reported that food expenditure is related to income. The food expenditure increased with the rise of income during the period from 1970 to 1997 (Putnam and Allshouse, 1999). Therefore, the relationship between obesogenic materials and food expenditures demonstrates the health conditions for specific demographic groups. For example, negative relationship between food expenditure and obesogenic materials demonstrates that poor population is much easier to be obesity than rich population.

However, are consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures different, or the same?

In the previous research, consumers' decisions on fat and carbohydrates with respect to food prices and expenditures are believed as the same as that of calories, since calories is major in forms of fat and carbohydrates. So, they only study consumers' decisions on obesogenic materials separately. Nevertheless, since these three major obesogenic materials play different roles in the process of metabolism and food consumption, we believe that people should focus on different major obesogenic materials when they are purchasing food. Therefore, we argue consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures might be different. Hence, we aim to study consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures simultaneously, to determine the interactions among consumers' decisions.

## 1.4 RESEARCH QUESTIONS

As mentioned above, in the previous research, consumer's reactions to obesogenic materials have been studied separately. For example, Cutler et al. (2003) estimate consumers' decisions on calories with respect to food price, but do not include the effect of fat or carbohydrates. Chouinard et al. (2005) research the effect of price on fat consumption in dairy products. In addition, a fat tax has been imposed on particular foods (e.g. snack food and soft drinks) to reduce fat consumption in many countries, such as the US. This approach assumes that the impact of nutrients on obesity is identical regardless of the source. Therefore, a fat tax may simply cause consumers to substitute carbohydrates for fat, having little impact on obesity. However, obesogenic materials have different adverse effects in the process of metabolism and different contents in various food categories. Therefore, it is important to study these three major obesogenic materials simultaneously to develop effective policies to control obesity.

Given this purpose, we aim to determine consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures in different food categories. In this way, the interactions among obesogenic materials can be deduced, and information related to the impacts of a composite commodity tax on changes in material consumption can be estimated. Therefore, we propose the following research questions:

a) What are the food price and expenditure elasticities of calories, fat, and carbohydrates in different food categories?
b) What are the interactions among these three materials?
c) What conclusions can we draw from the elasticities?
d) What kind of policy implications can we find for controlling obesity?

## 1.5 Organization

The rest of this thesis is organized as follows: Section 2 provides a literature review, which summarizes and synthesizes the methods and results of the existing relevant research. Section 3 describes our data source and discusses our data limitation. Section 4 illustrates the model and method. Section 5 reports our data analysis and results. Section 6 concludes with the results and offers some policy recommendations.

# CHAPTER 2 Literature Review

In this chapter, the literature review is divided into five sub-sections. The first sub-section explains the relationship between body weight and material intakes. The second sub-section discusses researched material selection in the literature. Next sub-section introduces the composite good theories. The fourth sub-section reviews the types of nutrient proportion, including fixed proportion and variable proportion in composite goods in different studies. The last sub-section describes different models applied in the literature, and discusses the application of models.

## 2.1 BODY WEIGHT VS. MATERIAL INTAKES

To study the impact of food price on obesity phenomenon, economists either examine the relationship between food price and body weight or between food price and material consumption. Lakdawalla and Philipson (2002), Chou et al. (2004), Auld and Powell (2008), Sturm and Datar (2005 and 2008), and Goldman (2009) have studied the relationship between food price and body weight. Cutler et al. (2003), Chouinard et al. (2005), and Clark and Levedahl (2006) have examined the relationship between food price and material consumption. The following two parts describe these studies, respectively.

### 2.1.1 Body Weight

Table 2 shows a literature review matrix to summarize previous studies about body weight.

Table 2 Literature review matrix for body weight

| Authors | Publish Year | Country | Sample Period | Target Population | Research Question | Results | Limitations |
|---|---|---|---|---|---|---|---|
| Lakdawalla and Philipson | 2002 | US | 1988 – 1994 | Young adults | What are the effects of agriculture food prices and job-related exercise on the body weight (BMI)? | (1) 40% of recent growth in body weight results from **lower** agriculture food prices; (2) 60% of the growth is from other demand factors, such as **reduced** physical activity. | (1) Do not know how food consumption contributes to obesity through material intakes. (2) Cannot provide an effective tax policy on food to control obesity. |
| Chou et al. | 2004 | US | 1984 – 1999 | Adults | What is the relationship between body weight (BMI) and prices at restaurants, food consumed at home, cigarettes, and alcohol? | (1) Per capita number of restaurants is **positively** related to growth in body weight; (2) Body weight is **negatively** related to food; (3) **Higher** cigarettes price result in **higher** body weight. | |
| Sturm and Datar | 2005 & 2008 | US | 1998 – 1999 | Children | How do the prices of meats, fruits, and vegetables related to body weight (BMI)? | (1) The meat price is **negatively** related with body weight; (2) The price of fruits and vegetables are **positively** related with body weight. | |
| Auld and Powell | 2008 | US | 1997 – 2003 | Adolescents | How are the prices of high energy-dense food (e.g. meats) and low energy-dense food (e.g. vegetables) related to body weight (BMI)? | (1) A **negative** association between price of high energy-dense food and body weight; (2) A **positive** association between price of low energy-dense food and body weight. | |

Lakdawalla and Philipson (2002) study the effects of food prices and job-related exercise on the body weight of the US young adults from 1988 to 1994. In their research, BMI is used to measure the body weight. They find that the lower food prices, led to around 40% of the recent increase in body weight. The other 60% is due to other demand factors, such as physical activity reduction.

Since 1970's, the US obesity population increases dramatically. To examine the factors which contribute to the significant prevalence rate, Chou et al. (2004) study the relationship between the US adult body weight and prices of restaurant foods, food consumed at home, cigarettes, and alcohol from 1984 to 1999. BMI is applied in their research. They conclude that a large positive association between the per capita number of restaurant visits and the trend of obesity since 1970's. They show a negative relationship between food prices and body weight. They also find that the higher cigarette price, the higher BMI. Therefore, they believe the anti-smoking campaign, which causes higher cigarette price, is associated with the trend of obesity.

Unlike Lakdawalla and Philipson (2002) and Chou et al. (2004), Sturm and Datar (2005 and 2008) study the association between the US children's body weight and the prices of two groups of foods between 1998 and 1999. The first group is meats, which is an example of high energy-dense food. The other is fruits and vegetables, which is a typical instance of low energy-dense food. They also use BMI to measure body weight. In the results, they find that meat price is negatively related with children's body weight. Second, the relationship between children's body weight and fruits and vegetables is significantly positive.

As with Sturm and Datar (2005 and 2008), Auld and Powell (2008) divide their study into two parts. They estimate the relationship between adolescent body weight and the price of high energy-density food (e.g. meat and fast food), and estimate the relationship between adolescent body weight and the price of low energy-density food (e.g. fruit and vegetables). The data is from the US between 1997 and 2003. BMI is studied again. Their results demonstrate a negative relationship between price of high energy-dense food and adolescent body weight, and a positive relationship between price of low energy-dense food and adolescent body weight.

From Table 2, we clearly see that these four papers determine the impact of different food prices on the body weight of different research populations in the US. All of them use BMI as a measure of body weight. No matter what the research population is, their results are consistent: (1) for high energy-density food, such as meat and fast food, price is negatively related with body weight; (2) for low energy-density food, like fruits and vegetables, price is positively related with body weight. That is because high energy-density food and low energy-density food substitute into each other. For example, if price of low energy-density food increases, consumers would purchase less low energy-density food and more high energy-density food.

### 2.1.2 Material consumption

In the study by Cutler et al. (2003), they focus on the effect of energy consumption (i.e. calories consumption) on obesity from 1960s to 1990s. They conclude that more calories consumption is the major reason for the growth in obesity, not less exercise. Furthermore, they believe that technological innovations in food production and food transportation, cause people to consume more calories consumption. The innovations make foods mass production and make food transportation quickly. This decreases the time costs of foods, leading to more food consumption. There are, of course, other facts consistent with the theory, such as the increase of food variety, eat more times per day, and regulations for food industry. Table 3 shows a literature review matrix to summarize previous studies about material consumption and material selection.

Table 3 Literature review matrix for material consumption and selection

| Authors | Publish Year | Country | Sample Period | Target Population | Material | Research Question | Results | Limitations |
|---|---|---|---|---|---|---|---|---|
| Cutler et al. | 2003 | US | 1960s - 1990s | Individuals | Calories | What is the effect of energy intake on the growth in obesity? | (1) **More calories intake** is the major reason of the growth in obesity; (2) More calories intake is due to the **technological innovations** in food production and food transportation, which reduce the time costs of food. | (1) Do not estimate those obesogenic materials simultaneously to obtain the interactions among them. |
| Chouinard et al. | 2005 | US | Jan.1997 – Dec. 1999 | Households | Substitute dairy products for fat | What is the effect of "fat tax" on the fat consumption in dairy products across different demographic groups? | (1) The effect of "fat tax" on fat consumption is **not significant**; (2) The effect of "fat tax" on welfare is **large and vary dramatic** across demographic groups, especially for the elderly and poor populations. | |
| Clark and Levedahl | 2006 | US | 1980 - 2000 | Individuals | Fat and Calories | What are the price and income elasticities of fat in meats? | (1) The compensated own-price elasticities of meats show that "fat tax" might **increase** the total fat consumption. | |

Chouinard et al. (2005) study the effect of fat tax on the US household demand of dairy products across different demographic groups from Jan. 1997 to Dec. 1999. They also examine the elasticities of fat consumption by applying the dairy elasticities of demand. They choose to use dairy elasticities of demand because they assume the dairy elasticities of demand and the underlying fat elasticities of demand are fixed and constant. We will discuss this material proportion problem in Section 2.4. They find those elasticities are relatively low and vary little across different demographic groups. Hence, they conclude the impact of a fat tax on fat consumption is ineffective because the dairy elasticities of demand are low. However, the effect of "fat tax" on welfare is large and vary dramatic across demographic groups. For example, the elderly and poor populations suffer more health welfare losses, because of lower income.

Clark and Levedahl (2006) study the food price and income elasticities of fat from the US meat market during the period from 1980 to 2000, to find the "fat tax" influence on individual body weight. In order to determine the elasticities, they estimate the impact of price and income on both fat per calories and total fat consumption. Fat per calorie here means the fraction of calories eat as fat. The compensated own-price elasticities of meats tell us that "fat tax" might increase the total fat consumption rather than reduce it.

From Table 3, although all these three papers focus on the effect of food price on the consumption of obesogenic materials in the US markets, they differ in materials, the material units, research methods, and their results. Their commonality is their focus on the impact of food price on material intakes rather than on the impact on body weight, so that the information associated with the influences of a composite commodity tax on changes in material consumption can be estimated. Nevertheless, more materials should be estimated, because the interactions among materials. We will discuss this in Section 2.2.

### 2.1.3 Comparison of Body Weight and Material consumption

In the introduction, the main factors associated with obesity are discussed. They are excess food consumption and reduced physical activities. In terms of food consumption, people consume the food first, and then their bodies take the energy from nutrients. The energy would contribute to body function, physical work and so on. Finally, the excess energy contributes to obesity. Therefore, the change of price affects food consumption directly, and affects body weight indirectly. Furthermore, studying more materials simultaneously can provide information related to the impact of a composite commodity tax on changes of material consumption. Hence, we study obesogenic materials simultaneously to know how food prices and expenditures affect obesity.

## 2.2 MATERIAL SELECTION

In the introduction, we have briefly discussed the selection of materials that is important to the control of obesity. We believe that consumers' decisions on calories, fat, and carbohydrates intake should be made simultaneously. Nevertheless, in the previous research, the consumers' decisions are evaluated separately. Cutler et al. (2003) study consumers' decision of calories intake with respect to food price, but do not consider the effect of fat or carbohydrates. Furthermore, the estimated own price elasticity on calories is statistically insignificant. They argue that given the lack of scientific consensus, so they ignore the effect of fat, carbohydrates and other factors such as income and wage. However, from the information of metabolism from Bender's work (2008), we know fat and carbohydrates do jointly affect body weight. Chouinard et al. (2005) only examine the effect of price on fat consumption in dairy products. In addition, they regard the dairy products consumption as fat consumption, so the result is not accurate to represent that for fat consumption. Clark and Levedahl (2006) use "fat per calories" and "total fat consumption" as material units. They consider both calories and fat, but ignore carbohydrates.

As mentioned above, the serious prevalence of obesity has led to a call to implement policies to control or mitigate obesity. A fat tax could be an example. The policy of fat tax has been imposed on particular food groups (e.g. snack food and soft drinks) to reduce fat consumption and obesity population in many countries, such as the US. However, how about the other obesogenic materials? The obesogenic materials have different adverse effects in the process of metabolism and have different compositions in various food categories. Hence, it is important to study these three materials simultaneously to develop effective policies to control obesity.

## 2.3 FIXED *VS.* VARIABLE PROPORTIONS

Different researchers hold different opinions on the obesogenic material content in foods. Beatty and Lafrance (2005) assume that material proportion in each composite commodity is fixed. However, Reed et al. (2003) and Clark and Levedahl (2006) show that materials consumed in each composite commodity is variable with the change of price (see Section 2.3.2). Table 4 briefly shows the comparison between "fixed proportions" and "variable proportions".

Table 4 Literature review matrix for materials proportions

| Author | Publish Year | Materials Proportions |
|---|---|---|
| Beatty and Lafrance | 2005 | **Fixed** Proportions |
| Reed et al. | 2003 | **Variable** Proportions |
| Clark and Levedahl | 2006 | **Variable** Proportions |

### 2.3.1. Fixed Proportions

Beatty and Lafrance (2005) study the impacts of policies on food demand, material consumption, and consumer welfare across income, ethnicity, and age population groups with Price Independent Generalized Linear (PIGL) and Price Independent Generalized Logarithmic (PIGLOG) models of consumer demand. They first demonstrate the formulas of the price and income elasticities of demand for food items. Then, in order to determine the price and income elasticities of demand for materials, they assume the relationship between food quantity and nutrient demand is linear. That is

$$\boldsymbol{z}=\boldsymbol{N}\boldsymbol{q}, \tag{3}$$

where $\boldsymbol{z}$ is the vector of materials in foods, $\boldsymbol{N}$ is a matrix of material content per unit of food, and $\boldsymbol{q}$ is a vector of food quantities. Equation (3) assumes that the material content per unit of food does not change, that is, the percentage of one material in a particular food is fixed, so we call it "fixed proportions" material demand.

### 2.3.2 Variable Proportions

Reed et al. (2003) study the elasticities of demand, quantity, and quality by the applications of the Generalized Composite Commodity Theorem (GCCT) and the

Generalized Addilog Demand System (GADS). Their estimated elasticities show that fat consumed is “variable proportions” rather than “fixed proportions”.

Clark and Levedahl (2006) report that material consumed is “variable proportions”. They estimate price and income elasticities of calories and fat from meats with the GADS model. They illustrate that materials consumed in each composite group change as the price, so it is “variable proportions”.

### 2.3.3 Comparison of Fixed and Variable Proportions

In one composite food, material consumption in elementary goods may vary. For example, in dairy products, the fat content in yogurt is lower than that in cream. Since the consumption quantity of each elementary good would change as the food prices change, the composite quality (i.e. materials in one composite food) would change as well. Hence, we argue that “fixed proportions” materials demand is too restrictive to capture true consumer choices. In addition, results from Reed et al. (2003) and Clark and Levedahl (2006) indicate that materials demand is “variable proportions” rather than “fixed proportions” of composite foods.

## 2.4 MODELS

Researchers use different economic models in their study. Beatty and Lafrance (2005) study the impacts of policies on food demand, material consumption, and consumer welfare across income, ethnicity, and age population groups using Price Independent Generalized Linear (PIGL) and Price Independent Generalized Logarithmic (PIGLOG) models. Reed et al. (2003) and Clark and Levedahl (2006) use the Generalized Addilog

Demand System (GADS) model to estimate consumers' decisions in respond to the changes in the income and meat price. Chouinard et al. (2005) use the Almost Ideal Demand System (AIDS) to estimate the effect of "fat tax" on the fat consumption in dairy products across different demographic groups. In the AIDS, price is regarded as exogenous and quantity is regarded as endogenous. In contrast, in the Inverse Almost Ideal Demand System (IAIDS), price is treated as endogenous and quantity is treated as exogenous (Holt and Balagtas, 2009). Holt and Balagtas (2009) apply the IAIDS to determine the US meat demand. Table 5 shows the list of models.

Table 5 Literature review matrix for models

| Author | Publish Year | Model |
|---|---|---|
| Beatty and Lafrance | 2005 | Price Independent Generalized Linear (**PIGL**) and Price Independent Generalized Logarithmic (**PIGLOG**) |
| Reed et al. | 2003 | Generalized Addilog Demand System (**GADS**) |
| Clark and Levedahl | 2006 | |
| Chouinard et al. | 2005 | Almost Ideal Demand System (**AIDS**) |
| Holt and Balagtas | 2009 | Inverse Almost Ideal Demand System (**IAIDS**) |

However, so many economic models cannot all fit for the restrictions in the GCCT and Nelson/Theil model (see Section 3.1). Since our research purpose is to determine consumers' decisions on calories, fat, and carbohydrates with respect to food price and expenditures, rather than test the availability of demand models, we decide to use the simplest double logarithm to estimate the elasticities of food price and expenditures.

# CHAPTER 3 Model and Method

In this chapter, we discuss the model and estimation methods for the composite commodity demand elasticity estimation. First of all, we review the composite good theories which are related to food and nutrition demand. Given these theories, we use the double logarithm and the seemingly unrelated regressions (SUR) to estimate the price and expenditure elasticities of obesogenic materials. Finally, we show the relationships among elasticities.

## 3.1 Composite Good Theories

In this section, we review the Theil model and Nelson/Theil model. They are related to quality (e.g. obesogenic materials) and quantity, and composite good theories. The composite good theories contain Composite Commodity Theorem (CCT) and Generalized Composite Commodity Theorem (GCCT).

We should clarify the basic concepts associated with composite good theories. In this research, we study the change of obesogenic material consumption with the change of food prices. Composite good is defined as the heterogeneous good, like fruits and vegetables, beef, eggs, meats, and dairy products. Beef includes lean ground beef, porter house steak, ribs, etc. as the subclasses of the composite commodity beef in the data. And those lean ground beef, porter house steak, ribs, etc. are called elementary goods, which is defined as homogenous good. In most research about food demand, some level of product aggregation must be implemented.

The data used in this thesis are for composite goods because it is more practical to assume that government would impose a tax on a composite good rather than an elementary good. Furthermore, studying composite food could better solve the problem of substitutions among elementary goods. However, improper aggregation, like over aggregation and under aggregation, would lead to biased results, such as biased estimated elasticities and biased estimation of welfare loss related with public policies. Therefore, carefully deal with aggregation data is necessary (see the Chapter 4).

### 3.1.1 The Theil Model

Theil (1952 - 1953) proposed the first well-known economic analysis by quality variation. Theil assumed the composite commodity quantities as the sum of the physical quantities of elementary goods in each group. In addition, Theil added "quality" choice as a separate set of elements in the household utility function,

$$\text{Max U } (q_1, q_2, \dots, q_G, \dots q_M, v_1, v_2, \dots, v_G, \dots, v_M)$$

$$\text{s.t.} \sum_{G=1}^{M} p_G(v_G) q_G = Y,$$

$$q_G = \sum_{i \in G} x_i, \qquad (4)$$

where $q_G$ is consumed physical quantity of commodity $G$, $v_G$ is the quality of commodity G, $p_G$ is the composite price which corresponding to composite quality, Y is household income, M is the number of composite commodity groups, and $x_i$ is consumed quantity of elementary good $i$ in a composite commodity group G. In this study, the quality choice could be calories, fat, and carbohydrates. Theil model shows the relationships between quality and quantity. However, Theil cannot solve this model without the Composite

Commodity Thorem (CCT), because Theil model needs the assumption of fixed price movement proportion in CCT to solve the optimization of both quantity and quality.

### 3.1.2 Composite Commodity Theorem (CCT)

Hick and Leontief (1936) proposed a Composite Commodity Theorem (CCT) as a method for consistent aggregation of elementary to composite commodities. The theorem says that if the prices of a group of elementary goods move in the same proportion with respect to the original prices, then the group of elementary goods behaves just like a single commodity. That is, for any two elementary goods in a composite good, their prices move in the same proportion. So, scholars could treat a composite commodity as a single commodity to study. The CCT simplifies a very complex problem into a lower dimensional space system, which is between any composite good and money (i.e. purchasing power).

### 3.1.3 The Nelson/Theil Model

By the application of CCT, the Theil model could be solved. However, as pointed out by Nelson (1991), there are several problems with Theil's model. She proposes a modification so that she proposed the Nelson/Theil model. The first and most important issue is an ambiguity about how the quantities, $q_G$, associates to the "quantity demanded" of consumer demand theory. In the standard demand theory, quantity demanded is a function of exogenous prices and income, while the quantities, $q_G$, in Theil's model, depending on quality choice (Nelson, 1991).

The second problem is the measurement (i.e. unit) of physical quantity. Physical quantity can be measured by weight, volume, nutrient content, and others. However, measurement in different physical quantity dimensions could offer contradictory solutions. For example, as incomes increase, consumers would buy more Häagen-Dazs ice cream, which has less air-filled and more density, than other ice creams. As a result, if the measurement is volume, the income elasticity of physical demand is negative. If the measurement is weight, the income elasticity of physical demand is positive. Thus, is Häagen-Dazs ice cream inferior or normal good? Hence, the selection of measurement of physical quantity should be carefully considered.

The third problem is how these physical quantities relate to any item of real interest. For example, farmers and agricultural policy planners may be interested in physical quantities by weight. And nutritionist may be interested in physical quantities by nutrient contents rather than weight.

The last problem is about the assumption about price movement. Theil (1952-1953) used the CCT, which assumes the prices of all elementary goods in a composite commodity group move together in the same proportion with respect to the original prices to solve his model. As mentioned above, this assumption is too restrictive.

After examining the problems of the Theil model, Nelson (1991) proposal her model for utility maximization in choosing composite goods:

$$\text{Max U } (Q_1, Q_2, \dots, Q_G, \dots, Q_M)$$
$$\text{s.t. } \sum_{G=1}^{M} P_G Q_G = Y, \qquad (5)$$

where $Q_G$ is the composite commodity quantities, $P_G$ is the composite commodity price. The CCT assumes that the prices of all elementary goods within each composite group G vary proportionally. Namely,

$$i \in G \;\Rightarrow p_i = P_G p_i^*, \tag{6}$$

where $p_i$ is the price of elementary good $x_i$, $p_i$* is the "base" price of good $x_i$, and $P_G$ also can be regarded as the factor of proportionality common to all elementary goods in group *G*. According to the Hick's CCT, a composite commodity is defined as:

$$Q = \sum_{i \in G} p_i^* x_i. \tag{7}$$

The composite commodity quantity depends on the composite commodity prices and income, as shown in equation (8).

$$Q_G(P, Y), \tag{8}$$

where *P* is the vector of $P_G$'s. In this way, the elasticity of $Q_G$ in terms of $P_G$ is the own price elasticity for composite commodity *G*. The elasticity of $Q_G$ in terms of *Y* is the income elasticity. According to the above information, the expenditure and unit value for the group G can be calculated as:

$$E_G \equiv \sum_{i \in G} p_i x_i = \sum_{i \in G} (P_G p_i^*) x_i = P_G \sum_{i \in G} p_i^* x_i = P_G Q_G; \tag{9}$$

$$\text{and } V_G \equiv E_G / q_G = P_G Q_G / q_G \;, \tag{10}$$

where $E_G$ is expenditure in group G, and $V_G$ is the unit value in group G.

Since a quantity weighted sum of elementary goods base prices can be regarded as a measure of average quality within a group, quality can be calculated as:

$$v_G \equiv \sum_{i \in G} (x_i / q_G) p_i^* = \sum_{i \in G} p_i^* x_i / q_G = Q_G / q_G, \tag{11}$$

where $v_G$ is the quality of group G.

By these inferences, we can summarize the above information using the following three simple identities:

$$Q_G = v_G q_G; \tag{12}$$

$$E_G = P_G v_G q_G; \tag{13}$$

$$\text{and } V_G = P_G v_G. \tag{14}$$

Equation (12) shows that the decomposition of composite demand is composite quality and quantity. This assumes that "quantity" is the only characteristics that consumers value when they make decisions. It could be kilogram, gram, liter, etc.. Clark and Levedahl (2006) expand the composition of composite demand in equation (12) into a variety of characteristics:

$$Q_G = \prod_{j=1}^{k} v_G^j; \tag{15}$$

$$\text{and } Q_G = O_G K_G F_G C_G, \tag{16}$$

where $K$ is number of characteristics, $j$ means the $j$-th quality characteristic, $O_G$ is the other composite quality characteristics, $K_G$ is the composite characteristic of calories, $F_G$ is the composite characteristic of fat, and $C_G$ is the composite characteristic of carbohydrate. Equation (16) is a specialization of equation (15) that includes the obesogenic material characteristics of calories, fat, and carbohydrates.

By enhancing the Theil model to the Nelson/Theil model using the CCT, we obtain a demand theory, which explains the relationship between quantity and quality. However, few people believe the CCT and thereby the Nelson/Theil model, until the GCCT is proposed.

### 3.1.4 Generalized Composite Commodity Theorem (GCCT)

It seems implausible the within group prices move in exact tandem as required by the CCT (Lewbel, 1996; Reed et. al., 2004). The strong assumption is price movement, restricts the prices within a group to remain fixed over time, and hence is rejected (Lewbel, 1996; Reed et. al., 2004). Furthermore, the aggregation based on weak separability is often false (Reed et. al., 2004).

Lewbel (1996) described that the Generalized Composite Commodity Theorem (GCCT) imposes weaker and more empirically plausible restrictions on price movements and improves the requirement that independence among all groups is held. Furthermore, the GCCT permits the aggregation without separability (Lewbel, 1996). The GCCT could be applied to many utility functions, like the AIDS model, the translog, all homothetic utility functions, and any utility function when demands are aggregated into two groups of goods (Lewbel, 1996). Therefore, the GCCT has revived the Nelson/Theil model.

### 3.1.5 Summary of Composite Good Theories

The rejection to the proportional price movement restriction confines the application of the Nelson/Theil model (Reed et al., 2003). Nobody would like to use the Nelson/Theil model until 1996, because the GCCT was proposed at that time. The GCCT revives the Nelson/Theil model, because of the more plausible restrictions of the GCCT (Reed et al., 2003).

The literature provides both theories of composite demand and statistic for our study. The Nelson/Theil model provides a composite demand theory which relates quantity with quality. And the GCCT allows our study to focus on stochastic rather than non-stochastic, which provides a statistic theory.

According to the above, taking natural logarithms of equation (12) and differentiating with respect to natural logarithms of food price or food expenditure, we obtain the food price and food elasticities are obtained:

$$\beta_Q = \beta_v + \beta_q; \tag{17}$$

$$\text{and } \gamma_Q = \gamma_v + \gamma_q, \tag{18}$$

where $\beta_x$ is the food price elasticity of a variable $x$, and $\gamma_x$ is the food expenditure elasticity of a variable $x$. Table 6 shows our discussion about composite good theories.

Table 6 Summary of composite good theories

| Author | Publish Year | | Discussion | |
|---|---|---|---|---|
| | | Theory | Problems | Advantages |
| Hicks and Leontief | 1936 | Composite Commodity Theorem (CCT) | (1) Too strong price movement restriction; (2) Weakly separability. | - |
| Theil | 1952-1953 | Theil's model | (1) How quantities relate to consumer demand theory; (2) The measurement of physical quantity; (3) How quantities relate to any item of real interest; (4) Price movement assumption from CCT. | - |
| Nelson | 1991 | Nelson/Theil model | - | (1) Relate quantities to consumer demand theory; (2) Provide the relationships among those elasticities; (3) Offer a new model which better explain the composite commodity demand system. |
| Lewbel | 1996 | Generalized Composite Commodity Theorem (GCCT) | - | (1) Weaker and more empirically plausible restrictions on price movements; (2) Aggregation without separability. |
| Reed et al. | 2003 | - | **(1) CCT is rejected, so Nelson/Theil model is rejected; (2) However, the application of GCCT revives Nelson/Theil model.** | |
| Clark and Levedahl | 2006 | - | **(1) The physical unit of measurement could be used to define quantity; (2)The decomposition of composite demand includes a variety of characteristics.** | |

## 3.2 DOUBLE LOGARITHM

In our study, we are interested in consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures. We assume that food prices and expenditures are regressors. And consumptions of calories, fat, and carbohydrates in every composite commodity are regressands, respectively. Using the logarithm on both sides of equation (19), we obtain

$$ln\, y_{Gt} = \alpha_{Gt} + \sum_{H=1}^{M} \beta_{GHt}\, ln\, P_{Ht} + \gamma_{Gt}\, ln\, I + u_{Gt},$$

$$G\ and\ H = 1, 2, \ldots, M;\ t = 1, 2, \ldots, N;\ \text{and} \qquad (19)$$

$$I = FE/AP, \qquad (20)$$

where $y_{Gt}$ is one of the consumptions of calories, fat, and carbohydrates in one composite commodity, $H$ and $G$ both mean one composite commodity, $P_{Ht}$ is the food price of one composite commodity, $I$ is real food expenditure which is expressed in equation (20), $FE$ is nominal food expenditure, and $AP$ is the aggregated price for all items. Note that $P_{Ht}$ and $AP$ are different. $P_{Ht}$ means the food price of one composite commodity, while $AP$ is the aggregated price for all items.

From equation (19), we can see that $\beta_G$ and $\gamma_G$ are food price and expenditure elasticities of obesogenic material consumption. Although the regressors for each obesogenic material in each composite commodity are the same, dependent variables (i.e. obesogenic materials) are different. So, if we use the Ordinary Least Square (OLS) model, we have to repeat running regressions for different composite commodities and different nutrients. To improve the efficiency of estimation, we use the Seemingly Unrelated Regressions (SUR) model, which improves efficiency by accounting for correlations among errors of equations.

## 3.3 The Seemingly Unrelated Regressions (SUR)

In our research, we can divide dependent variables into three groups: calories, fat, and carbohydrates. To explain the SUR, take calories as an example. In general, SUR model is written as:

$$\boldsymbol{K} = \boldsymbol{X}\boldsymbol{B} + \boldsymbol{u}; \tag{21}$$

$$\text{and} \begin{bmatrix} \boldsymbol{K}_1 \\ \boldsymbol{K}_2 \\ \vdots \\ \boldsymbol{K}_M \end{bmatrix} = \begin{bmatrix} \boldsymbol{X}_1 & 0 & \dots & 0 \\ 0 & \boldsymbol{X}_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \boldsymbol{X}_M \end{bmatrix} \begin{bmatrix} \boldsymbol{B}_1 \\ \boldsymbol{B}_2 \\ \vdots \\ \boldsymbol{B}_M \end{bmatrix} + \begin{bmatrix} \boldsymbol{u}_1 \\ \boldsymbol{u}_2 \\ \vdots \\ \boldsymbol{u}_M \end{bmatrix}, \tag{22}$$

where $\boldsymbol{K}$ is a $M \times 1$ vector of $\boldsymbol{K}_G$, which is a $N \times 1$ vector of calories contents for each composite good in various years; $\boldsymbol{X}$ is a $M \times M$ matrix of $\boldsymbol{X}_G$, which is a $N \times (2 + M)$ matrix of regressors for each composite good in various years; $\boldsymbol{B}$ is a $M \times 1$ vector of $\boldsymbol{B}_G$, which is a $N \times 1$ vector of parameters for each composite good in various years; $\boldsymbol{u}$ is a $M \times 1$ vector of $\boldsymbol{u}_G$, which is a $N \times 1$ vector of random disturbances for each composite good in various years. Equation (22) is an expansion of equation (21), which more specifically presents the SUR model for calories. From the above equations, we clearly see that there are $M$ equations in the SUR model for calories.

For this model, there are three assumptions: (1) strict exogeneity of $\boldsymbol{X}_G$, (2) homoscedasticity, and (3) contemporaneous correlation (Greene, 2008). Greene (2008) assumes that all random disturbances are expected to be zeros, namely exogeneity. In addition, he assumes that disturbances are uncorrelated across observations, while they are correlated across equations. Thereby, we have the assumptions of exogeneity, homoscedasticity and contemporaneous correlation:

$$\text{Exogeneity: } E[\boldsymbol{u}] = \mathbf{0}; \tag{23}$$

$$\text{Homoscedasticity: } E[\boldsymbol{u}_G\boldsymbol{u}_G'] = \sigma_{GG}\boldsymbol{I}_N; \tag{24}$$

$$\text{and Contemporaneous correlation: } E[\boldsymbol{u}_G\boldsymbol{u}_H'] = \sigma_{GH}\boldsymbol{I}_N. \tag{25}$$

For both heteroscedasticity and autocorrelation in the SUR model, efficient estimation requires the Generalized Least Square Regression (GLS) be applied to equation (21) given equations (23), (24), and (25) (Greene, 2008). So, for one observation, the variance-covariance matrix is given by

$$\boldsymbol{\Sigma} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1M} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{M2} & \sigma_{M2} & \cdots & \sigma_{MM} \end{bmatrix}, \tag{26}$$

where $\boldsymbol{\Sigma}$ is an $M \times M$ variance covariance matrix, so the overall variance covariance matrix is

$$\boldsymbol{\Omega} = \boldsymbol{\Sigma} \otimes \mathbf{I}, \tag{27}$$

where $\otimes$ is the Kronecker Product, and $\boldsymbol{\Omega}$ is the $MN \times MN$ overall variance covariance matrix. Thus, the GLS estimator is

$$\begin{aligned} \widehat{\mathbf{B}} &= [\mathbf{X}'\boldsymbol{\Omega}^{-1}\mathbf{X}]^{-1}\mathbf{X}'\boldsymbol{\Omega}^{-1}\mathbf{K} \\ &= [\mathbf{X}'(\boldsymbol{\Sigma}^{-1} \otimes \mathbf{I})\mathbf{X}]^{-1}\mathbf{X}'(\boldsymbol{\Sigma}^{-1} \otimes \mathbf{I})\mathbf{K}, \end{aligned} \tag{28}$$

where $\widehat{\mathbf{B}}$ is an $MN \times 1$ vector of parameters estimates.

However, in Section 3.1, we have mentioned that the regressors are identical in these *M* equations. So,

$$\boldsymbol{X}_1 = \boldsymbol{X}_2 = \cdots = \boldsymbol{X}_M = \overline{\boldsymbol{X}}, \tag{29}$$

where $\overline{\boldsymbol{X}}$ is the identical regressors. In this case, the GLS and the OLS are identical, because $\boldsymbol{X}_i'\boldsymbol{X}_j = \overline{\boldsymbol{X}}'\overline{\boldsymbol{X}}$ for all G and H (Greene, 2008). Thus, the OLS estimator is

$$\widehat{\boldsymbol{B}} = [\boldsymbol{I} \otimes (\overline{\boldsymbol{X}}'\overline{\boldsymbol{X}})^{-1}\overline{\boldsymbol{X}}']\boldsymbol{K}. \tag{30}$$

Finally, we obtain the food price and food expenditure elasticities from the OLS estimator.

## 3.4 Relationships Among Elasticities

In Section 2.3, we demonstrated the relationships of elasticities and the decompositions of composite demand. Now, we will apply them into our research.

From equation (16), we know the decompositions of composite demand are other quality, calories, fat, and carbohydrates. So, the composite expenditure is

$$E_G = P_G O_G K_G F_G C_G. \tag{31}$$

Taking natural logarithm of equation (16) and (31), and differentiating with respect to natural logarithm of food prices or expenditures, the food price and expenditure elasticities and their relationships are obtained:

$$\beta_Q = \beta_O + \beta_K + \beta_F + \beta_C, \quad (32)$$

$$\text{and } \gamma_Q = \gamma_O + \gamma_K + \gamma_F + \gamma_C, \quad (33)$$

where $\beta_Q$ is food price elasticity of composite demand, $\beta_O$, $\beta_K$, $\beta_F$, and $\beta_C$ are food price elasticities of other quality, calories, fat, and carbohydrates, respectively, $\gamma_Q$ is food expenditure elasticity of composite demand, $\gamma_O$, $\gamma_K$, $\gamma_F$, and $\gamma_C$ are food expenditure elasticities of other quality, calories, fat, and carbohydrates, respectively, Equations (32) and (33) separately show the food price and expenditure elasticities relationships among composite demand, other quality, calories, fat, and carbohydrates.

The above equations show the flexibility of the signs of elasticities. It means that, as long as they satisfy the relationships among elasticities, the positive or negative for the signs of elasticities does not really matter. However, the price elasticity of demand is an exception, because of the law of demand. For example, the price elasticity of composite demand is negative, but the price elasticities of calories, fat, and carbohydrates could be either positive or negative, as long as they satisfy equation (32).

# CHAPTER 4 Data

We use two data sources in this study. From Bureau of Labor Statistics (BLS) (1984-2006), we obtain the expenditures for all food and the Consumer Price Index (CPI) for each composite good and all items. From the Center for Nutrition Policy and Promotion (CNPP) (1984-2006), we obtain the consumption of calories, fat, and carbohydrates for each composite good. Note that the unit of calories in our data is a kilocalorie. To avoid confusion, we unify the term as calories. The first section illustrates the food category selection from different data sources. The next section describes the data for each characteristic and data processing. And the last section discusses the limitations of our data.

## 4.1 Food Aggregation

Between the BLS and CNPP, food aggregations are not exactly the same. Since we need data from both sources, we should choose the food categories carefully. The food categories in the BLS should match those of CNPP as closely as possible. We choose 7 food categories: (1) cereals and bakery products, (2) meats, poultry, and fish, (3) eggs, (4) fresh fruits and vegetables, (5) sugar and other sweets, (6) fats and oils, and (7) dairy products.

## 4.2 Characteristics

In the BLS, there are two kinds of data characteristics available. One is average annual expenditures for different items per consumer unit. The definition of a consumer unit could be any of the following: (1) a person living alone or sharing a household with others or living as a roommate in a private home or lodging house or in permanent living quarters in a hotel or motel, but who is financially independent; (2) two or more persons living together who use their incomes to make joint expenditure decisions; (3) all members of a particular household who are related by blood, marriage, adoption, or other legal arrangements. We collect the expenditure for all foods, which includes food at home and food away from home. Since we need to obtain the average annual food expenditures for each person, we use expenditure for foods divide by the average number of persons in a consumer unit:

$$FE = \frac{Expenditure\ for\ foods}{Average\ number\ of\ persons\ in\ a\ consumer\ unit}, \tag{34}$$

where *FE* is food expenditure per person. All the expenditure data are available from 1984 to 2009.

The other data from the BLS is Consumer Price Index (CPI). We select the CPI for all urban consumers on the US city average. There are two kinds of CPI available. One is seasonally adjusted, and the other one is not seasonally adjusted. Since data collection history of the former is shorter than that of the latter, and the collection history of the former is not long enough to be used in this thesis, we use the latter for those 7 composite goods and all items from 1984 to 2009. And then we normalize the CPI by the CPI in 1984 as following:

$$P_{G1984} = \frac{CPI\ for\ one\ composite\ good\ in\ 1984}{CPI\ for\ one\ composite\ good\ in\ 1984}; \tag{35}$$

$$P_{G1985} = \frac{CPI\ for\ one\ composite\ good\ in\ 1985}{CPI\ for\ one\ composite\ good\ in\ 1984} \text{ ; and} \tag{36}$$

$$AP = \frac{CPI\ for\ all\ items}{CPI\ for\ all\ items\ in\ 1984}\ , \tag{37}$$

where $P_{G1984}$ is the real food price of group G in 1984, $P_{G1985}$ is the real food price of group G in 1985, and $AP$ is aggregated price for all items.

The CNPP data start from 1909 to 2006, and the BLS data start from 1984 to 2009. To obtain the maximum sample size, we select the data range from 1984 to 2006. First, we collect the percentage of each nutrient contribution in each composite food per person. Then, we collect the amount of total consumption for each nutrient per person. Thus, we calculate the amount of calories, fat, and carbohydrates consumptions in each composite good per person using the following equation:

$$K_G = percentage\ of\ calorie\ in\ one\ composite\ food \\ \times the\ amount\ of\ total\ consumption\ for\ calorie\ per\ person\ . \tag{38}$$

In summary, our data contain: (1) food expenditure per person, (2) CPI for 7 composite goods based on the year of 1984, (3) CPI for all items based on the year of 1984, and (4) the consumption amounts of calories, fat, and carbohydrates for 7 composite goods per person. All these data are from 1984 to 2006, namely, there are 23 observations in this research.

In the material consumption, obesogenic materials in some food categories are zero. In the fats and oils category, the carbohydrates consumption percentage is zero. Moreover, in the sugar and other sweets category, the fat consumption percentage is also zero. So, we exclude the columns that are zeros in the SUR model estimation.

## 4.3 Data Limitations

If data were available by cohort or panel data were available, more information regarding the effects across age, gender, area, etc. would be obtained. For example, consumers behaviour in different age groups are not the same, because of their different demand in regard to health condition and interest. Consumers behaviour for different income groups are also not the same, because of their income and social status. However, our data from the CNPP do not have the information for different demographic groups. For this limitation, we only can study the aggregate US consumer behaviour.

As we mentioned above, the consumers behaviour for different age groups are different. In a family, there are children, parents, and the elderly. So, the unit of household is suggested to be investigated rather than the unit of individual. Nevertheless, the CNPP data do not offer the household material consumption information. Because of this limitation, we only can study the individual material consumption rather than the household material consumption.

The third point is the number of observations. If the data were available by month or quarterly, more observations would be obtained. It is helpful for obtaining more accurate and precise results. However, the CNPP only has annual data about obesogenic materials. Thereby, the results are limited by this point.

Finally, the difference between consumption and intake also is a limitation of the data. Foods may be wasted not consumed, so the obesogenic material consumption cannot well represent the obesogenic material intakes. Hence, the results might be biased for this limitation.

These four limitations limit our interpretation and the data, so that they cannot explain more phenomenons. We expect these limitations can be solved in the future, which could contribute more to this study area.

# CHAPTER 5 Results

In this chapter, we first examine our data through two graphs. And then, we analyze the econometrics model and then estimation results in detail.

## 5.1 PRELIMINARY RESULTS

Figure 3 shows the changes of three obesogenic materials consumption from 1984 to 2006: 1) Calories consumption; 2) Fat consumption; 3) Carbohydrates consumption.

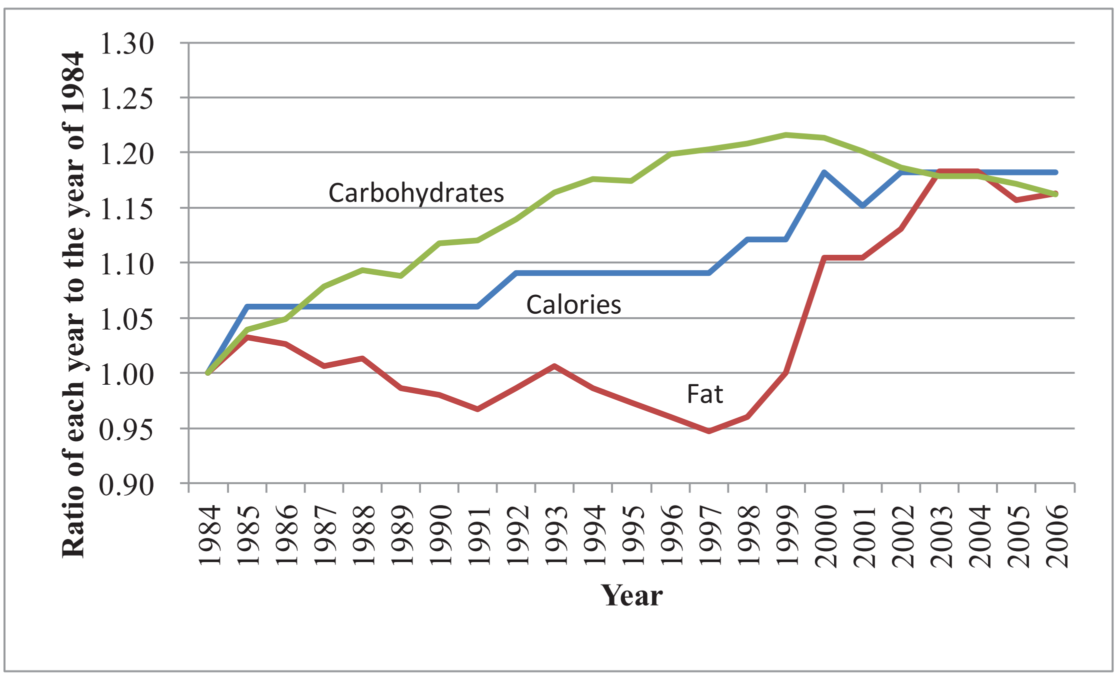


Figure 3 The changes of consumptions of calories, fat, and carbohydrates from 1984 to 2006. (Data Source: BLS and CNPP, various years)

Figure 4 shows the changes of food CPI and real food expenditure from 1984 to 2006.

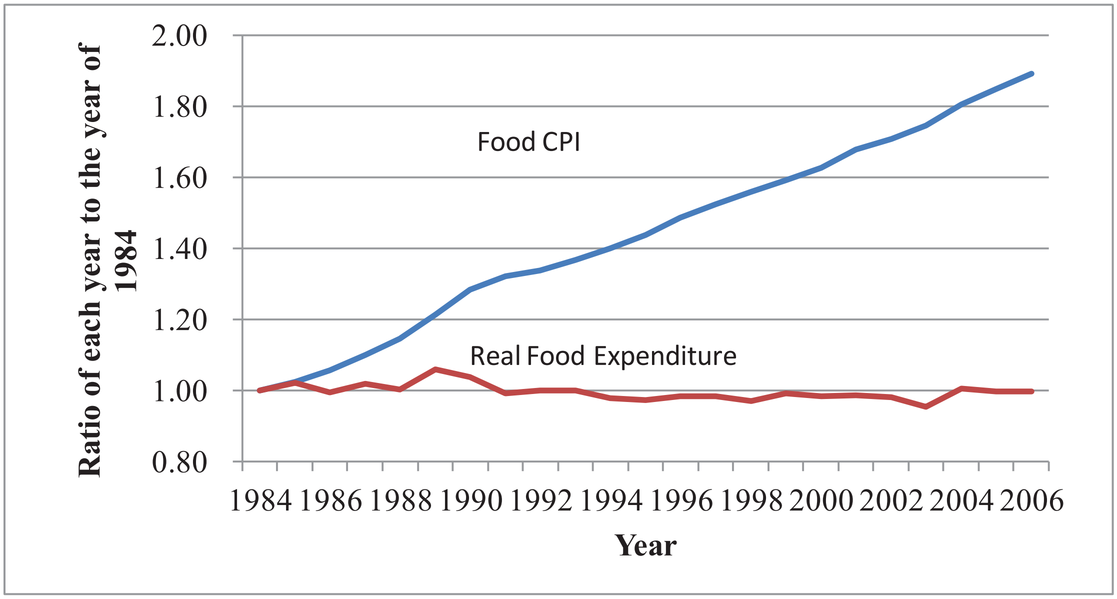


Figure 4 The changes of food CPI and real food expenditure from 1984 to 2006. (Data Source: BLS and CNPP, various years)

As the base year is 1984, all the changes in Figure 3 and 4 have the same start point of 1. Figure 3 demonstrates that the major obesogenic material consumption change in the different patterns but end at the almost same ratio. Carbohydrate consumption keeps increases dramatically from the beginning of the sample time period to the year of 2000 and then drops a little to 1.17. Calorie consumption gradually increases with a relative slow speed in the whole period to 1.18. From year 1984 to 1998, fat consumption falls 0.05 with a fluctuation, but significantly rises to 1.17 from 1998 to 2006. Figure 4 illustrates that the real food expenditure in the whole sample time period is almost constant except a little fluctuation. But the food CPI increases dramatically. At the end of the period, the food CPI almost doubles.

From Figure 3 and 4, we find consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures are indeed different. However, these preliminary results through figures only tell us the overall results. They mask lots of detail, which only can be provided by the econometrics model and methods. For example, with using the econometrics model and methods, we see the consumers' decisions on obesogenic materials with respect to food prices and expenditures in each food category. But the preliminary results cannot show that.

## 5.2 Econometric Results

In this section, we firstly talk about the R-Squared and Durbin-Watson of calories, fat, and carbohydrates in 7 food categories. Then, we discuss the food expenditure and own price elasticities. Finally, we describe the price elasticities of calories, fat, and carbohydrates for the whole food group in terms of different food prices and recommend some policy options. Tables 7, 8, and 9 show the food price and expenditure elasticities in 7 food categories of calories, fat, and carbohydrates, respectively. Tables 7, 8, and 9 also contain the coefficients of R-Squared and Durbin-Watson.

Table 7 Food price and expenditure elasticities of calories in 7 food categories

| Regressor natural logarithm of | Calories | | | | | | |
|---|---|---|---|---|---|---|---|
| | Cereals and Bakery products | Meats, poultry, and fish | Eggs | Fresh fruits and vegetables | Sugar and other sweets | Fats and oils | Dairy products |
| Constant | 2.015 | 6.472** | 7.914*** | 4.587** | 4.867*** | 18.296*** | 3.436** |
| | [1.56] | [2.61] | [3.15] | [2.43] | [4.09] | [3.68] | [2.31] |
| Cereals and Bakery products price | **0.668*** ** | -0.898** | -0.964** | 0.350 | 0.641** | -0.489 | -0.219 |
| | **[3.41]** | [-2.39] | [-2.53] | [1.23] | [3.55] | [-0.65] | [-0.97] |
| Meats, poultry, and fish price | -0.076 | **0.236** | -0.143 | -0.265 | -0.719*** | 1.591*** | -0.375** |
| | [-0.62] | **[1.02]** | [-0.61] | [-1.50] | [-6.43] | [3.42] | [-2.68] |
| Eggs price | -0.104** | -0.025 | **-0.062** | -0.048 | -0.096** | -0.312* | 0.028 |
| | [-2.36] | [-0.30] | **[-0.72]** | [-0.75] | [-2.36] | [-1.83] | [0.56] |
| Fresh fruits and vegetables price | 0.076 | 0.192 | 0.210 | **-0.255** | 0.275* | -0.981* | 0.042 |
| | [0.54] | [0.71] | [0.77] | **[-1.24]** | [2.12] | [-1.81] | [0.26] |
| Sugar and other sweets price | 0.492 | -0.262 | 0.058 | 0.685 | **-0.110** | -0.492 | 1.021** |
| | [1.45] | [-0.40] | [0.09] | [1.39] | **[-0.35]** | [-0.38] | [2.61] |
| Fats and oils price | -0.517** | -0.278 | -0.648 | -0.212 | -0.308 | **-0.170** | -0.042 |
| | [-2.20] | [-0.62] | [-1.42] | [-0.62] | [-1.42] | **[-0.19]** | [-0.15] |
| Dairy products price | -0.347** | 0.917*** | 1.362*** | -0.012 | 0.151 | 1.825*** | **-0.371*** |
| | [-2.28] | [3.15] | [4.62] | [-0.05] | [1.08] | [3.13] | **[-2.12]** |
| Real food expenditures | **0.638*** ** | **-0.025** | **-0.553** | **0.039** | **0.211** | **-1.646*** ** | **0.342** |
| | **[3.54]** | **[-0.07]** | **[-1.58]** | **[0.15]** | **[1.27]** | **[-2.38]** | **[1.65]** |
| R-squared | **0.969** | **0.651** | **0.698** | **0.568** | **0.955** | **0.826** | **0.765** |
| Durbin-Watson | **1.838** | **1.699** | **1.889** | **1.911** | **1.892** | **1.946** | **2.724** |

Note: The values in brackets are t-value. (* p<0.10, ** p<0.05, *** p<0.01)

Table 8 Food price and expenditure elasticities of fat in 7 food categories

| Regressor natural logarithm of | Fat | | | | | |
|---|---|---|---|---|---|---|
| | Cereals and Bakery products | Meats, poultry, and fish | Eggs | Fresh fruits and vegetables | Fats and oils | Dairy products |
| Constant | -5.604** | 5.549 | 7.505*** | 26.302** | 16.955*** | -0.350 |
| | [-2.45] | [1.76] | [4.33] | [2.92] | [3.57] | [-0.15] |
| Cereals and Bakery products price | **1.847*** ** | -0.947* | -0.772** | -1.757 | -0.194 | -0.478 |
| | **[5.33]** | [-1.98] | [-2.94] | [-1.29] | [-0.27] | [-1.33] |
| Meats, poultry, and fish price | 0.352 | **0.509** | 0.014 | 0.608 | 1.674*** | -0.619** |
| | [1.64] | **[1.72]** | [0.09] | [0.72] | [3.75] | [-2.77] |
| Eggs price | -0.284*** | 0.071 | **-0.041** | 0.097 | -0.265 | 0.078 |
| | [-3.63] | [0.66] | **[-0.69]** | [0.32] | [-1.63] | [0.96] |
| Fresh fruits and vegetables price | -0.542** | 0.282 | -0.052 | **-0.946** | -0.962* | 0.298 |
| | [-2.18] | [0.82] | [-0.27] | **[-0.96]** | [-1.86] | [1.15] |
| Sugar and other sweets price | -0.219 | -1.298 | -0.100 | 0.906 | -1.060 | 1.338* |
| | [-0.37] | [-1.57] | [-0.22] | [0.38] | [-0.85] | [2.14] |
| Fats and oils price | 0.329 | -0.672 | -0.310 | -0.269 | **-0.329** | -0.277 |
| | [0.79] | [-1.18] | [-0.98] | [-0.16] | **[-0.38]** | [-0.64] |
| Dairy products price | -1.023*** | 1.477*** | 1.293*** | 2.926** | 1.896*** | **-0.397** |
| | [-3.81] | [3.99] | [6.34] | [2.76] | [3.39] | **[-1.42]** |
| Real food expenditures | **0.941** ** | **-0.253** | **-0.869*** ** | **-3.761*** ** | **-1.763** ** | **0.469** |
| | **[2.95]** | **[-0.58]** | **[-3.59]** | **[-2.99]** | **[-2.66]** | **[1.41]** |
| R-squared | **0.932** | **0.767** | **0.819** | **0.759** | **0.835** | **0.698** |
| Durbin-Watson | **1.375** | **1.614** | **1.929** | **2.489** | **1.874** | **3.066** |

Note: The values in brackets are t-value. (* p<0.10, ** p<0.05, *** p<0.01)

Table 9 Food price and expenditure elasticities of carbohydrates in 7 food categories

| Regressor natural logarithm of | Carbohydrates | | | | | |
|---|---|---|---|---|---|---|
| | Cereals and Bakery products | Meats, poultry, and fish | Eggs | Fresh fruits and vegetables | Sugar and other sweets | Dairy products |
| Constant | 1.423 | -2.589** | -2.589** | 2.995 | 4.546*** | 2.387 |
| | [1.07] | [-2.46] | [-2.46] | [1.64] | [3.57] | [1.42] |
| Cereals and Bakery products price | **0.899*** ** | 0.806*** | 0.806*** | 0.862*** | 0.899*** | 0.816*** |
| | **[4.46]** | [5.06] | [5.06] | [3.11] | [4.66] | [3.19] |
| Meats, poultry, and fish price | -0.020 | **-0.308*** ** | -0.308*** | -0.188 | -0.674*** | -0.088 |
| | [-0.16] | **[-3.13]** | [-3.13] | [-1.10] | [-5.64] | [-0.56] |
| Eggs price | -0.047 | -0.027 | **-0.027** | 0.097 | -0.049 | 0.101 |
| | [-1.03] | [-0.76] | **[-0.76]** | [1.54] | [-1.12] | [1.75] |
| Fresh fruits and vegetables price | 0.114 | 0.125 | 0.125 | **-0.013** | 0.298** | -0.230 |
| | [0.79] | [1.09] | [1.09] | **[-0.07]** | [2.15] | [-1.25] |
| Sugar and other sweets price | -0.003 | -0.215 | -0.215 | -0.412 | **-0.579** | -0.302 |
| | [-0.01] | [-0.78] | [-0.78] | [-0.86] | **[-1.73]** | [-0.68] |
| Fats and oils price | -0.715** | -0.499** | -0.499** | -1.104*** | -0.485* | -0.463 |
| | [-2.96] | [-2.62] | [-2.62] | [-3.33] | [-2.10] | [-1.51] |
| Dairy products price | -0.238 | -0.024 | -0.024 | 0.368 | 0.238 | **-0.176** |
| | [-1.52] | [-0.19] | [-0.19] | [1.71] | [1.59] | **[-0.89]** |
| Real food expenditures | **0.503** ** | **0.239** | **0.239** | **0.059** | **0.071** | **0.115** |
| | **[2.71]** | **[1.63]** | **[1.63]** | **[0.23]** | **[0.40]** | **[0.49]** |
| R-squared | **0.967** | **0.958** | **0.958** | **0.663** | **0.952** | **0.851** |
| Durbin-Watson | **1.923** | **1.808** | **1.808** | **1.469** | **1.751** | **1.764** |

Note: The values in brackets are t-value. (* p<0.10, ** p<0.05, *** p<0.01)

### 5.2.1 R-Squared and Durbin-Watson

R-Squared and Durbin-Watson are two coefficients used to describe the regression. R-Squared describe how good the regression model predicts movements in the variables. And Durbin-Watson tells us whether there is autocorrelation issue in the regression.

First of all, let us look at the R-Squared of calories, fat, and carbohydrates in 7 food categories. It is shown in Tables 7, 8, and 9.We find that the correlations in all equations are strong (higher than 0.6) except the one of calories in fresh fruits and vegetables. It is only 0.568, just less than 0.6, so the correlation is moderate. In those strong correlations, some are even higher than 0.9, which means very strong. Hence, the regression model in this study well predicts movements in the explained variables.

Next, let us look at the Durbin-Watson of calories, fat, and carbohydrates in 7 food categories. Almost all of the Durbin-Watson values are in the "no conclusion zone", which p-value ranges from 0.47 to 2.67. Although the value of fat in the dairy products is closed to $d_L$ in terms of negative autocorrelation, it is still in the "no conclusion zone". The values of fat in the fresh fruits and vegetables and of calories and fat in the dairy products point out that there are not positive autocorrelations in these equations. Therefore, the autocorrelation issue in this study is ambiguous but safe.

Given R-Squared and Durbin-Watson values, we know that the regression model in this study is reasonable, reliable, and usable.

## 5.2.2 Food expenditure and Own Price Elasticities

In this sub-section, we describe and discuss the food expenditure and own price elasticities. Table 10 summarizes the food expenditure elasticities of calories, fat, and carbohydrates in 7 food categories from Tables 7, 8, and 9.

Table 10 Food expenditure elasticities of calories, fat, and carbohydrates in 7 food categories

| Food categories | Calories | Fat | Carbohydrates |
|---|---|---|---|
| **Cereals and bakery products** | 0.638*** | 0.941** | 0.503** |
| | [3.54] | [2.95] | [2.71] |
| **Meats, poultry, and fish** | -0.025 | -0.253 | 0.239 |
| | [-0.07] | [-0.58] | [1.63] |
| **Eggs** | -0.553 | -0.869*** | 0.239 |
| | [-1.58] | [-3.59] | [1.63] |
| **Fresh fruits and vegetables** | 0.039 | -3.761*** | 0.059 |
| | [0.15] | [-2.99] | [0.23] |
| **Sugar and other sweets** | 0.211 | N/A | 0.071 |
| | [1.27] | [N/A] | [0.40] |
| **Fats and oils** | -1.646** | -1.763** | N/A |
| | [-2.38] | [-2.66] | [N/A] |
| **Dairy products** | 0.342 | 0.469 | 0.115 |
| | [1.65] | [1.41] | [0.49] |

Note: The values in brackets are t-value. (* $p<0.10$, ** $p<0.05$, *** $p<0.01$)

According to Table 10, the obesogenic material consumption would contribute to obesity problem with respect to different food expenditure level populations in four food categories:

(1) cereals and bakery products, (2) eggs, (3) fresh fruits and vegetables, and (4) fats and oils.

In the cereals and bakery products, the food expenditure elasticities of calories, fat, and carbohydrates are all positive and statistically significant. It means that rich people consume more obesogenic materials from cereals and bakery products than poor people.

In the eggs, the food expenditure elasticities of calories and carbohydrates are not statistically significant. However, the food expenditure elasticity of fat is negative and statistically significant. It means that poor people consume more obesogenic materials from eggs than rich people.

In the fresh fruits and vegetables, the food expenditure elasticities of calories and carbohydrates are positive and not statistically significant, but that of fat is negative and statistically significant. So, we think that poor people consume more obesogenic materials from fresh fruits and vegetables than rich people.

In the fats and oils, all of the food expenditure elasticities are negative and statistically significant. Therefore, poor people consume more obesogenic materials from the fats and oils than rich people.

In each food categories of meats, poultry, and fish, eggs, and fresh fruits and vegetables, consumers' decisions on calories, fat, and carbohydrates with respect to food expenditures are different. For the meats, poultry, and fish, as well as eggs, the food expenditure elasticities of calories and fat are negative, but that of carbohydrates is positive. For the fresh fruits and vegetables, the food expenditure elasticities of calories and carbohydrates are positive, but that of fat is negative.

In summary, different food expenditure level populations faces different obesogenic material consumption in terms of different food categories. Rich people consume more obesogenic materials from the cereals and bakery products, but poor people consume more from the eggs, fresh fruits and vegetables, and fats and oils. Furthermore, in the food categories of meats, poultry, and fish, eggs, and fresh fruits and vegetables, consumers' decisions on calories, fat, and carbohydrates with respect to food expenditures are different.

Now, let us look at Table 11, which summarize the own price elasticities of calories, fat, and carbohydrates in 7 food categories from Tables 7, 8, and 9.

Table 11 Own price elasticities of calories, fat, and carbohydrates in 7 food categories

| Food categories | Calories | Fat | Carbohydrates |
|---|---|---|---|
| **Cereals and bakery products** | 0.668*** | 1.847*** | 0.899*** |
| | [3.41] | [5.33] | [4.46] |
| **Meats, poultry, and fish** | 0.236 | 0.509 | -0.308*** |
| | [1.02] | [1.72] | [-3.13] |
| **Eggs** | -0.062 | -0.041 | -0.027 |
| | [-0.72] | [-0.69] | [-0.76] |
| **Fresh fruits and vegetables** | -0.255 | -0.946 | -0.013 |
| | [-1.24] | [-0.96] | [-0.07] |
| **Sugar and other sweets** | -0.110 | N/A | -0.579 |
| | [-0.35] | [N/A] | [-1.73] |
| **Fats and oils** | -0.170 | -0.329 | N/A |
| | [-0.19] | [-0.38] | (N/A) |
| **Dairy products** | -0.371** | -0.397 | -0.176 |
| | [-2.12] | [-1.42] | [-0.89] |

Note: The values in brackets are t-value. (* p<0.10, ** p<0.05, *** p<0.01)

By and large, Table 11 shows that cereals and bakery products is "low quality" food in terms of calories, fat, and carbohydrates, but the meats, poultry, and fish, as well as dairy products are "high quality" food.

In the cereals and bakery products, the own price elasticities of calories, fat, and carbohydrates are all statistically significant positive. Therefore, it is "low quality" food in terms of these three obesogenic materials.

In the meats, poultry, and fish, the own price elasticity of calories and fat are positive and not statistically significant, but that of carbohydrates is statistically significant negative. So, the category of meats, poultry, and fish are "high quality" food. In addition, in this food category, consumers' decision on calories, fat, and carbohydrates with respect to own price are different.

In dairy products, the own price elasticity of fat and carbohydrates are not statistically significant, nevertheless, that of calories is statistically significant negative. So, dairy products is also "high quality" food.

In eggs, fresh fruits and vegetables, sugar and other sweets, and fats and oils, the own price elasticities of calories, fat, and carbohydrates are all negative and not statistically significant, so the price changes of these food categories do not influence the obesogenic materials consumption.

In summary, cereals and bakery products is "low quality" food, and the meats, poultry, and fish as well as dairy products are "high quality" food. Furthermore, consumers' decision on calories, fat, and carbohydrates with respect to own price are different in the category of meats, poultry, and fish.

According to the results from Table 10 and 11, we find consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures are different. It proves that we do need to be concerned about material selection in this area of study because the results of a single nutrient research would be misleading. Furthermore, as we expected, our results show that a composite commodity tax could work effectively on controlling material consumption.

First, as shown in Table 11, obesogenic materials are positively related to own prices in cereals and bakery products, so imposing a composite commodity tax on cereals and bakery products ought to be not effective for leading markets to an opposite direction. Second, due to different consumers' decision on the meats, poultry, and fish, imposing a composite commodity tax on this food category also suppose to be not effective for the offset effects. Third, in addition to cereals and bakery products as well as meats, poultry, and fish, obesogenic materials are negatively related to own food prices. Thereby, a composite commodity tax on these food categories might be effective.

### 5.2.3 Price Elasticities for the whole food group

Nevertheless, only the own price elasticities are not enough to explain our results. So, next, to analyze the results comprehensively, we will analyze the price elasticities of calories, fat, and carbohydrates for the whole food group in terms of different food prices, which consider both own and cross price elasticities, are shown in Table 12.

Table 12 The price elasticities of calories, fat, and carbohydrates for the whole food group in terms of different food prices

| Regressor natural logarithm of | Calories | Fat | Carbohydrate |
|---|---|---|---|
| **Cereals and Bakery products price** | -0.911 | -2.301 | 5.088 |
| **Meats, poultry, and fish price** | 0.249 | 2.538 | -1.587 |
| **Eggs price** | -0.619 | -0.343 | 0.047 |
| **Fresh fruits and vegetables price** | -0.441 | -1.922 | 0.419 |
| **Sugar and other sweets price** | 1.393 | -0.433 | -1.726 |
| **Fats and oils price** | -2.174 | -1.528 | -3.765 |
| **Dairy products price** | 3.525 | 6.173 | 0.143 |

Note: the whole food group means the sum of the 7 food categories.

According to Table 12, the prices of cereals and bakery products, eggs, as well as fresh fruits and vegetables are negatively related to the consumptions of calories and fat in the whole food group, but positively related to the consumption of carbohydrate. In contrast, the price of meats, poultry, and fish is positively related to the consumptions of calories and fat, but negatively related to the consumption of carbohydrate. In regards to the relationships between sugar and other sweets price and obesogenic material consumption, it is positive for calories, but negative for fat and carbohydrates. From the above, it is proved that consumers' decisions on calorie, fat, and carbohydrate to food prices are different. So, imposing composite commodity tax on these food categories would not be effective. Furthermore, it demonstrates that it is essential to analyze obesogenic materials simultaneously. In Table 12, when the price of fats and oils increases, all the material consumption drop. Hence, a composite commodity tax is highly recommended to be imposed on the fats and oils. However, when the price of dairy products increases, all the material consumption increases.

Therefore, imposing a composite commodity tax on dairy products is not effective. Furthermore, it will lead consumers' health to a harmful direction.

Compared with the results of own price elasticities, price elasticities for the whole food group, provide much different results because they including both own and cross price elasticities. Thereby, the cross price effect is important and cannot be ignored in this study. All the cross price elasticities are shown in Tables 7, 8, and 9.

Besides the information related to a composite commodity tax, we also find two interesting results. First of all, our results prove that food quality do not move with price in a fixed proportion, so material proportion in food should be variable rather than fixed, as we mentioned in the chapter of literature review. Next, imposing a composite commodity tax on fats and oils might reduce obesogenic material consumption for total population, but it might increase obesogenic material consumption for poor population. Since food expenditure elasticities in the fats and oils are negative, poor people, who cannot pay a large amount of food expenditure, would consume more calories and fat dramatically. As the limited food expenditure, they would choose cheaper fats and oils products which contain relatively higher calories and fat. So, poor population would consume much more obesogenic materials after "fats and oils tax".

# CHAPTER 6 Conclusion

As we expected, consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures are different. For the food prices of cereals and bakery products, meats, poultry, and fish, eggs, fresh fruits and vegetables, and sugar and other sweets, the effects of food prices on material consumption for the whole food group are ambiguous. Some are positive, and some are negative. They might be offset or not, as it is so complicated that it is difficult to tell their accurate effects on obesity growth. However, we can at least estimate their influences. Hence, it is essential to studying the obesogenic materials simultaneously.

In terms of the dairy products, all the price elasticities are positive. It illustrates that imposing a composite commodity tax on it would lead to a harmful direction. For the fats and oils, all the price elasticities are negative. Hence, we highly suggest the policy option of imposing a composite commodity tax on the fats and oils to control the obesity issue.

However, "fats and oils tax" might be benefit for the US total population, but harm to the US poor population. That is because the tax on the category of fats and oils might increase obesogenic material consumption in poor population. On one hand, we might see a significant reduction of obesity after the "fats and oils tax" in the whole country. However, on the other hand, we might see an increase of obesity in a particular population group. Hence, we cannot say the tax on the fats and oils is absolutely good or bad.

In the literature review, we discuss about material selection and material proportions. From the results, we could find some evidence to support our viewpoint. First, since consumers' decisions on calories, fat, and carbohydrates with respect to food prices and expenditures are different, materials selection should be important. The results of a single nutrient research, like the previous studies, might lead to a wrong direction to policy makers. It is shows that it is essential to study the obesogenic materials simultaneously. Second, those price and expenditure elasticities show that material proportion is variable rather than fixed. Understanding material proportion is importance and helpful for future study about composite commodity and obesogenic materials.

As mentioned in the data section, we have four data limitations, which limit our results and conclusions: 1) we only have the data for the average US population; 2) we only focus on individual; 3) we do not have many observations; and 4) we only have the material consumption data. In the future study, if we could improve these limitations and find better data, we believe that the results could be more reliable and convincible.

# BIBLIOGRAPHY

Auld, M. Christopher and Lisa M. Powell (2009). Economics of food energy density and adolescent body weight. Economica 76: 719-740.

Beatty, K. M. Timothy, and Jeffrey T. LaFrance (2005). "United States Demand for Food and Nutrition in the Twentieth Century," *American Agricultural Economics Association*, Vol. 87, No. 5, 1159-1166.

Bender, A. David (2008). "Introduction to Nutrition and Metabolism," Fourth edition, *CRC Press*, Taylor & Francis Group.

Bureau of Labor Statistics (1984-2006). "Consumer Expenditure Survey," United States Department of Labor. <http://www.bls.gov/cex/home.htm > (6 August 2011)

Bureau of Labor Statistics (1984-2006). "Consumer Price Index," United States Department of Labor. < http://www.bls.gov/cpi/home.htm > (6 August 2011)

Center for Nutrition Policy and Promotion (1984-2006). "Nutrient Content of the US Food Supply," United States Department of Agriculture. <http://www.cnpp.usda.gov/USFoodSupply.htm> (25 February 2011)

Centers for Disease Control and Prevention (2010). "Obesity and overweight". <http://www.cdc.gov/nchs/fastats/overwt.htm> (25 August 2011)

Chou, Shin-Yi, Michael Grossman, and Henry Saffer (2004). An economic analysis of adult obesity: results from the behavioral risk factor surveillance system. *Journal of Health Economics* 23(3): 565-578.

Chouinard, H. Hayley, David E. Davis, Jeffrey T. LaFrance, and Jeffrey M. Perloff (2005). "The Effects of a Fat Tax on Dairy Products," *Department of Agricultural & Resource Economics, UC Berkeley, Department of Agricultural & Resource Economics, UC Berkeley, Working Paper Series.*

Clark, J. Stephen, and William J. Levedahl (2006). "Will Fat Taxes Cause Americans to Become Fatter? Some Evidence from US Meats," *Contributed paper prepared for the presentation at the International Association of Agricultural Economists Conference*, Gold Cost, Australia.

Cutler, M. David, Edward L. Glaeser, and Jesse M. Shapiro (2003). "Why have Americans become more obese?" *National Bureau of Economic Research Working Paper,* No. 9446.

Deaton, Angus, and John Muellbauer (1983). "Economics and Consumer Behavior," *Published by the Press Syndicate of the University of Cambridge*, the Pitt Building, Trumpington Street, Cambridge CB2 1RP.

Goldman, Dana., Darius Lakdawalla, and Yuhui Zheng (2009). "Food prices and the dynamics of body weight," *National Bureau of Economic Research Working Paper*, No. 15096.

Greene, H. William (2008). "Econometric Analysis," sixth edition, *Pearson Prentice Hall*, printed in the United States of America.

Hicks, John R. (1936). "Value and capita," *Oxford: Oxford University Press*.

Holt, Matthew T. and Balagtas, Joseph V. (2009). "Estimating Structural Change with Smooth Transition Regressions: An Application to Meat Demand," *American Journal of Agricultural Economics*, Vol. 91, No. 5, 1424-1431.

Houthakker, H. S. (1952-1953). "Compensated Changes in Quantities and Qualities Consumed," *The Review of Economic Studies*, Vol. 19, No. 3, 155-164.

Jones, Timothy W. (2004). "Using Contemporary Archaeology and Applied Anthropology to understand Food Loss in the American Food System," *Bureau of Applied Research in Anthropology*, University of Arizona.

Lakdawalla, Darius and Tomas Philipson (2002). "Technological Change and the Growth of Obesity: A Theoretical and Empirical Examination." *National Bureau of Economic Research.*

Leontief, Wassily (1936). "Composite Commodities and the Problem of Index Numbers," *Econometrica*, Vol. 4, No. 1, 39-59.

Lewbel, Arthur (1996). "Aggregation without separability: a generalized composite commodity theorem," The American Economic Review, Vol. 86, No.3, 524-543.

Nelson, A. Julie (1991). "Quality Variation and Quantity Aggregation in Consumer Demand for Food," *American Agricultural Economics Association*, Vol. 73, No. 4, 1204-1212.

Putnam, J. J. and Allshouse, E. Jane (1999). "Food Expenditures and Income," *Food Consumption, Prices, and Expenditures, 1970-97*. United States Department of Agriculture, Economic Research Service.

Reed, J. Albert, William J. Levedahl, and Stephen J. Clark (2003). "Commercial Disappearance and Composite Demand for Food with an Application to US Meats," *Journal of Agricultural and Resource Economics*, Vol. 28, No. 1, 53-70.

Reed, A. J, J. W. Levedahl, and C. Hallahan (2004). "The Generalized Composite Commodity Theorem and Food Demand Estimation," *American Agricultural Economics Association Annual Meeting in Denver, Colorado, August*.

Sturm, R. and Datar, A. (2005). "Body mass index in elementary school children, metropolitan area food prices and food outlet density," *Public Health,* Vol. 119, No. 12, 1059-1068.

Sturm, R. and Datar, A. (2008). "Food prices and weight gain during elementary school: 5-year update," *Public Health*, Vol.122, No. 11, 1140-1143.

Theil, H. (1952-1953). "Qualities, Prices and Budget Enquiries," *The review of Economic Studies*, Vol. 19, No. 3, 129-147.

TeensHealth (2009). "Figuring Out Fat and Calories," *TeensHealth from Nemours*. <http://kidshealth.org/teen/food_fitness/nutrition/fat_calories.html#> (22 February 2011)

World Bank Data (2005). "Health Nutrition and Population Statistics," *The World Bank*. <http://databank.worldbank.org/ddp/home.do?Step=1&id=4> (22 February 2011)

World Health Organization (2011). "Obesity and Overweigh," *World Health Organization.* <http://www.who.int/mediacentre/factsheets/fs311/en/index.html> (28 March 2011)