The Environmental and Health Costs of Alternative Diets: A Comparative Study of the U.S. Diet Relative to the French, Japanese, Mediterranean, and Nordic Diets

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THE ENVIRONMENTAL AND HEALTH COSTS OF ALTERNATIVE DIETS: A COMPARATIVE STUDY OF THE U.S. DIET RELATIVE TO THE FRENCH, JAPANESE, MEDITERRANEAN, AND NORDIC DIETS

by

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This thesis contributes to the literature on sustainable consumption by using scenario analysis to evaluate the environmental and health costs of the U.S. diet relative to the French, Japanese, Mediterranean, and Nordic diets, identified in the literature as healthier diets. As a first step in estimating environmental costs, the energy efficiencies of each diet are calculated by decomposing each of the diets into their respective components. Then, the dietary efficiencies are translated into CO_2 emissions. As a first step in estimating health costs, a pooled cross-section time-series dataset is used to find the association between BMI and five countries, representative of the five diets. The costs are assessed using estimates in the literature of the social cost of carbon per ton and the health costs associated with an increase in BMI. Findings suggest that the U.S. diet is more environmentally costly than the Japanese and Mediterranean diets and less environmentally costly compared to the French and Nordic diets. All four alternative diets result in reduced BMI and, hence, reduced health costs compared to the United States. When aggregating the costs, the Mediterranean diet is the least costly when dietary compositions shifts, but total caloric consumption is held constant at the U.S. level. However, the Japanese diet is the least costly when both dietary composition and total caloric consumption are allowed to shift to the respective level in each diet.

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DEFINITION OF ABBREVIATIONS

ACCRA	American Chamber of Commerce Research Association
ADD	Average Danish Diet
NNR	Nordic Nutritional Recommendations
BMI	Body mass index
BRFSS	Behavioral Risk Factor Surveillance System
BTUs	British Thermal Units
CH_4	Methane
CLCA	Consequential life-cycle assessment
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
CPI	Consumer Price Index
DID	Differences-in-differences
DXA	Dual-energy x-ray absorptiometry
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization of the United Nations
GDP	Gross domestic product
GHGs	Greenhouse gases
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
LCA	Life-cycle assessment
N_2O	Nitrous oxide

NHANES	National Health and Nutrition Examination Survey
NLEA	Nutritional Labeling and Education Act
NND	New Nordic Diet
OECD	Organization of Economic Cooperation and Development
OLS	Ordinary least squares
SCC	Social cost of carbon
PPO	Preferred provider option
USDA	United States Department of Agriculture
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1 Motivation

This research is motivated by the idea of sustainable consumption, specifically as it pertains to a wider recognition of the impacts of consumption choices. This differs from sustainable production, the supply-side, producer-oriented approach to sustainability (Heller & Keoleian, 2003). The demand-side approach to sustainability has received increasing attention, mainly in Europe.

The term *sustainable consumption* emerged in the 1990s and has since been further defined and placed on the agenda of international organizations such as the United Nations and the Organization of Economic Cooperation and Development (OECD). Common to all definitions of sustainable consumption is the necessity of consuming more efficiently (differently and/or less) so that the needs of both present-day and future generations are met. This is the same emphasis in the Brundtland Commission's definition of sustainable development, defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission, 1987; quoted in Nordhaus, 1998, p.310). Meeting the needs of both present and future generations can be interpreted as an intergenerational application of the Pareto Principle, whereby "this generation should meet the needs of the present as long as there is no reduction in the ability to meet the needs of the future" (Nordhaus, 1998, p. 310).

Under the umbrella of sustainable consumption are sustainable diets, defined by the Food and Agricultural Organization of the United Nations (FAO) as

> those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources. (2010, p. 7)

Identifying such diets in practice, however, would be quite an undertaking as one would have to either have knowledge of all current diets worldwide and rank them based on the sustainability criterion listed in the FAO definition, or determine the optimal diet that meets such criterion and use it as a benchmark to compare the sustainability of current diets. As both approaches are holistic, their implementation would require an inordinate amount of information and knowledge of all the complex relationships between the different aspects of a sustainable diet.

The alternative to a holistic approach is a partial approach where the focus is on a subset of the various dimensions of sustainable diets. This research focuses on two of those dimensions: environmental and health. Specifically, a diet is considered more sustainable than another diet if it has the lesser cost associated with environmental and health damages.

Diet-related environmental damage results from the burning of fossil fuels, which releases greenhouse gases (GHGs) into the atmosphere, contributing to climate change. Fossil fuel energy is utilized in food production in the form of fertilizers, machinery, fuel, irrigation and pesticides (Pimentel & Pimentel, 2008). Different foods have different energy inputs and, therefore, dietary choice impacts the environment by varying degrees.

With respect to health damages, there are costs related to one's body mass index (BMI). Overconsumption of food, or a positive balance of energy consumed relative to energy expended, can lead to one being overweight or obese. Being overweight or obese, defined by BMI levels, is a risk factor for other non-communicable diseases. These diet-related conditions require treatment and, therefore, additional health costs.

The price consumers pay for food does not accurately reflect the full cost of food to society, i.e., the cost that reflects environmental and health costs (Institute of Medicine and National Research Council, 2012). However, if consumers are made aware of the full societal cost of their food consumption choices, the information may affect consumer preferences and, consequently, dietary choices in a direction than lessens damage to both the environment and health. A few studies have shown that, in addition to willingness to pay for privately appropriated attributes of food, like freshness, convenience, quality, and health benefits, consumers also are willing to pay for quasi-public attributes of food, like environmental performance (Seyfang, 2011; Sorqvist et al., 2013; Thilmany, Bond, & Bond, 2008). A goal of this research is to contribute to the measurement of such quasi-public food attributes that could be used in future research to gage consumers' willingness for pay for them.

1.2 Objectives

The primary objective of this research is to estimate the environmental and health costs associated with the average U.S diet compared to four representative diets around the world: Japanese, Mediterranean, French, and Nordic. These diets have been identified as being healthy dietary models (Adamsson et al., 2010; Duchin, 2005; Renaud & de Lorgeril, 1992). The average U.S. diet and the representative diets are defined as the food supplied per capita per day as reported by the Food and Agricultural Organization of the United Nations (FAO). FAO data is often used as a proxy for consumption in diet-related studies at the country level. Examples include Eshel and Martin (2006) and the U.S. Department of Agriculture's (USDA) Economic Research Service (2013) for the United States; and Tukker et al. (2011) for the European Union. In 2009, the average U.S. diet was characterized by a total daily intake of 3,688 kcal, 73 percent from plant-based products and the remaining 27 percent from animal-based products (FAO, 2013b).

The environmental costs considered are confined to carbon dioxide (CO_2) emissions at the production stage for each dietary component. The health costs considered include both medical and pharmaceutical costs associated with increases in BMI.

1.3 Organization of Work

Chapter 2 connects diet to the environment. Specifically, the amount of CO_2 emissions associated with the U.S. diet compared to the other four diets is estimated. Chapter 3 links diet to health by estimating the association between diet and BMI using pooled cross-section time-series data from the United States and the countries representing the four diets discussed in Chapter 2. Chapter 4 presents cost estimates of the four alternative diets, compares the tradeoffs between adopting different diets, and discusses the challenges in addressing the costs. A summary of the research is found in Chapter 5.

CHAPTER 2: DIET AND THE ENVIRONMENT

According to the most recent report by the Intergovernmental Panel on Climate Change (IPCC), anthropogenic climate change is now a widely accepted phenomenon (IPCC, 2013). Climate change occurs when greenhouse gases are emitted, and then trapped, in the atmosphere. “The majority of greenhouse gases come from burning fossil fuels to produce energy, although deforestation, industrial processes, and some agricultural practices also emit gases into the atmosphere” (U.S. Environmental Protection Agency, 2013a). Climate change is not only characterized by the warming of the Earth’s surface, but also by dramatic and unpredictable changes in weather patterns such as floods, droughts, or high winds. Climate change is a global issue and its effects are costly. A World Bank report estimates that a 2-degree Celsius increase in global temperature would result in $70 billion to $100 billion in annual adaptation costs between 2010 and 2050 (The World Bank, 2010). As defined by the IPCC, quoted in the report, adaption costs include “the costs of planning, preparing for, facilitating, and implementing adaption measures, including transaction costs” (p. 5).

This chapter explores the interrelationship between diet and the environment as a first step towards estimating the climate-related costs of different diets. The first section reviews related literature. The second section measures and compares the amount of CO_2 emissions embedded in the average French, Japanese, Mediterranean, Nordic, and U.S. diets and discusses its implications for climate change. The third section summarizes and concludes.

2.1 Related Literature

2.1.1 Energy Consumption and GHGs

Azzam (2012) compiles U.S. energy data and reports that since the 1950s, the U.S. food system used an average of 9.95 quadrillion British Thermal Units (BTUs) annually. This amount represents 14 percent of the total amount of energy consumed in the U.S. economy during the same time period. The average growth rate of total energy consumption in the United States between 1950 and 2007 was 28 percent, peaking at 101.3 quadrillion BTUs in 2007. The average growth rate of energy used by the food system was 34 percent during this same time period.

The agricultural sector in the United States produces food energy as well as biofuels energy, yet is also an energy consumer and, therefore, a net contributor to GHG emissions. Agricultural practices deplete soils of natural organic carbon through cultivation. However, depending on land use and management, soils are a medium of carbon sequestration, offsetting emissions due to fossil fuel use in production (West & Marland, 2002).

The IPCC's report on climate change attributes 13.5 percent of global GHG emissions to agriculture in 2004, excluding emissions from deforestation. Deforestation, or land-use change, would make the percentage substantially larger if included (IPCC, 2007a). In developed countries, the food sector is estimated to contribute 15 to 30 percent of GHG emissions (Vieux, Soler, Touazi, & Darmon, 2013). In the United States, agriculture accounts for 9 percent of emissions, according to the U.S. Environmental Protection Agency (EPA) (2013c). They report that GHG emissions have increased in the agricultural sector by 19 percent since 1990 due to the transition to liquid manure management systems in the livestock industry. The EPA notes that "unlike other economic sectors, agricultural sector emissions were dominated by N_2O emissions from agricultural soil management and CH_4 emissions from enteric fermentation, rather than CO_2 from fossil fuel combustion" (U.S. Environmental Protection Agency, 2013b, pp. ES-21). Therefore, by estimating only the CO_2 emissions associated with agricultural production, environmental damage and associated costs are understated. CO_2 is still relevant in the discussion. It is referred to as the "control knob" of climate change because it is highly concentrated in the atmosphere and lingers for hundreds of years (Lacis, Schmidt, Rind, & Ruedy, 2010).

A widely used approach to measure the environmental impacts of different products, including food, is a life-cycle assessment (LCA). LCA is a systems approach which follows the inputs and outputs of a product throughout each stage of its life (Scientific Applications International Corporation, 2006). When the food system is broken down by life-cycle stages, production accounts for a substantial portion of energy usage. Weber and Matthews (2008) report the on-farm production phase is associated with the most GHG emissions in the United States Based on an extensive literature review, Azzam (2012) finds on-farm energy has averaged 20 percent of total energy use in the food system since the 1950s. Over time, on-farm energy use has been declining. In 2002, the last year reported, on-farm energy use made up 14 percent of total energy consumption in the food system.

2.1.2 Energy and Food

Food is predominantly sourced from either animals or plants, fungi being the outlier. In ecological terminology, plant-based products such as fruits or vegetables are autotrophs, or primary producers, because they are able to convert energy from inorganic sources into nutrients for survival. Alternatively, animals are heterotrophs, or consumers, since they rely on other living organisms for their food energy. Consequently, animal-based products such as meat or dairy require more energy. Trophic levels help describe the energy flow through the food system. Averaged across animals and plants, one unit of food energy requires nine units of energy input (Azzam, 2012).

The literature on food energy is saturated with comparisons between animal-products and plant-based products. Pimentel and Pimentel (2008) find, on average, animal protein requires ten times the amount of energy inputs compared to grain protein. Table 2.1 shows the reported energy inputs needed to produce one energy unit of protein. Since the 1996 edition of Pimentel and Pimentel's book *Food, Energy, and Society*, beef production and egg production have both become more energy intensive, requiring more energy inputs relative to the energy output. All other livestock products and the livestock sector as a whole have become more efficient in terms of the ratio of energy inputs to energy outputs in the third edition published in 2008. For example, pork production energy efficiency has increased by a factor of seven.

Table 2.1

Reported Kcal Energy Inputs Required to Produce One Kcal of Protein

Livestock and Livestock Products	**Kcal Input:Kcal Protein[a] 1996 Edition**	**Kcal Input:Kcal Protein[b] 2008 Edition**
Lamb[c*]	188:1	**57:1**
Beef cattle[*]	**35:1**	40:1
Eggs	**28:1**	39:1
Pork	68:1	**14:1**
Milk	19:1	**14:1**
Chicken	16:1	**4:1**
Average	59:1	**28:1**

[a] Adapted from *Food, Energy, and Society* (p. 79), by D. Pimentel and M. H. Pimentel, 1996, Niwot, CO: University Press of Colorado.
[b] Adapted from *Food, Energy, and Society* (p. 69), by D. Pimentel and M. H. Pimentel, 2008, Boca Raton, FL: CRC Press.
[c] Lamb with a combination diet of grain and forage.
[d] Beef cattle with a combination diet of grain and forage.
* The animals' diets contribute to the energy expended in production. Pastured lamb and beef have lower fossil energy inputs (Pimentel & Pimentel, 1996).

2.1.3 GHG Emissions in Food and Diets

An often-cited source of livestock's contribution to environmental degradation is *Livestock's Long Shadow* (Steinfeld et al., 2006), published by FAO, which attributes 18 percent of global GHG emissions to livestock. Steinfeld et al. (2006) examine a number of emissions, including the three primary GHGs emitted in livestock production (CO_2, CH_4, and N_2O). The LCA method they use includes both direct emissions and indirect emissions[1]. The conclusions of *Livestock's Long Shadow* have motivated further research on the environmental impact of livestock production. Goodland and Anhang (2009) attribute 51 percent of global carbon emissions to livestock. Their report shows that the FAO report overlooks emission sources, including livestock respiration and land use. Additionally, methane is undercounted and some emissions, which could be

[1] As defined by Steinfeld et al. (2006), direct emissions are those coming directly from the animal's biological processes including respiration, digestion and waste. Indirect emissions are those resulting from pasturing livestock, producing feedcrops, land-use change and fossil fuel production used throughout the lifecycle of livestock products.

attributed to livestock, are misallocated to other sectors. Pitesky, Stackhouse, and Mitloehner (2009) find that 5.8 percent of GHG emissions in the United States can be attributed to agriculture and less than 3 percent to livestock production. The authors discuss the higher level of emissions in developing countries where forests are being cleared for rangeland. Additionally, agriculture is a small sector of the U.S. economy in comparison to the transportation, energy, and industry sectors. The motivation for Pitesky, Stackhouse, and Mitloehner's work is sustainability through efficiency and they contend that the U.S. system is a model that the rest of the world should follow. Another study by Capper (2011) measures emissions over time. Results show that between 1977 and 2007, the carbon emissions resulting from U.S. beef production decreased by 16.3 percent.

To compare GHG emissions associated with the bundle of food products that make up a diet, a scenario analysis methodology is frequently used. Researchers compare current diets to other alternatives, which may be based on semi-realistic hypothetical diets, recommended diets, or actual diets.

Extending their research beyond specific products, Marlow et al. (2009), Carlsson-Kanyama, Ekstrom, and Shanahan (2003), and Tukker et al. (2011) evaluate the environmental impacts of hypothetical diets. The study by Marlow et al. (2009) compares production inputs and concludes that a non-vegetarian diet is associated with higher environmental costs, especially when beef is included. Their results show that the non-vegetarian diet requires more water, primary energy[2], fertilizer, and pesticide inputs

[2] Primary energy sources are found in nature and can be used directly. Fossil fuels, biofuels, and solar energy are examples of primary energy sources. Primary energy transformed within an energy system is referred to as secondary energy. Examples include hydrocarbons, hydrogen, and electricity (Demirel, 2012).

by a factor of 2.9, 2.5, 13, and 1.4, respectively. The Swedish study by Carlsson-Kanyama, Ekstrom, and Shanahan (2003) uses a LCA method and determines energy inputs of hypothetical diets could vary by a factor of four.

Tukker et al. (2011) compare five diet groups in Europe to three alternative diets; a diet adhering to universal dietary recommendations, a diet meeting the recommendations with reduced meat consumption, and the Mediterranean-type diet with reduced meat consumption. Using E3IOT, an environmentally extended input-output model, and FAO food availability data, the researchers find that 27 percent of the environmental impact of household consumption can be attributed to food. They report that meat and dairy contribute over half of the food impact; consistent with other research showing that animal-based products determine the degree of environmental damage due to food. The environmental score is calculated as the weighted impact of abiotic resource depletion, climate change, ozone depletion, human toxicity, ecotoxicity, photochemical oxidant formation, terrestrial acidification, and freshwater eutrophication. A moderate reduction of animal-based products in one's diet, as exemplified by their alternative diets, could reduce environmental impact by up to 8 percent. The authors conclude that more drastic reductions of meat and dairy consumption are necessary to further reduce the impact of diets.

Also comparing hypothetical diets, Saxe, Larsen, and Mogensen (2013), Eshel and Martin (2006), and Carlsson-Kanyama (1998) focus on diet's impact on GHG emissions. Saxe, Larsen, and Mogensen (2013) compare the Average Danish Diet (ADD) to two other alternative diets; one based on Nordic Nutritional Recommendations (NNR) and the other termed the New Nordic Diet (NND). Both the NNR and NND are characterized by less animal-based products and the NND is comprised of local foods, more than 75 percent of which are organic. Using the consequential life cycle assessment (cLCA) method[3], they measure the global warming potential (GWP)[4] of each diet and find a reduction in animal-based products, specifically beef, in one's diet contributes to climate change mitigation. Compared to ADD emissions, GHGs are reduced in the NNR and NND by 8 percent and 7 percent, respectively, or 7 percent and 12 percent if transportation is included.

Eshel and Martin (2006) compare the average American diet to four hypothetical diets; a vegetarian diet (lacto-ovo), a diet in which fish is the only meat consumed (fish), a diet in which poultry is the only meat consumed (poultry), a diet in which a combination of 35.61 percent beef, 62.61 percent pork, and 1.78 percent lamb is consumed (red meat). In the first section, they compare the diets in terms of the CO_2 emissions emitted at the production stage. They find that the fish and red meat diets are the least efficient, followed by the average American diet, the poultry diet, and a vegetarian diet, in that order. When accounting for CH_4 and N_2O, the ranking (from least efficient to most) changes to: red meat, average American, fish, lacto-ovo, and poultry.

Carlsson-Kanyama (1998) compares the life-cycle energy use of six food products in Sweden and creates nutritionally equivalent diets. Findings indicate that a vegetarian diet emits 190 grams of CO_2-equivalents (CO_2e) where the mixed diets ranged from 380-1800 g of CO_2e.

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[3] Consequential life cycle analysis (CLCA) differs from attributional life cycle analysis (LCA) in that it incorporates economic concepts aiming to capture the effects of a decision beyond the physical flows. It requires more information such as marginal production costs and elasticities of supply and demand (Earles & Halong, 2011; Finnveden et al., 2009).

[4] The GWP is a metric used to compare the heat-trapping ability of GHGs in the atmosphere. The GWP for CO_2, CH_4, N_2O is 1, 25, 298, respectively over a 100 year period (IPCC, 2007b).

Rather than evaluate hypothetical diets, Coley, Goodliffe, and Macdiarmid (1998) study actual adult diets in the United Kingdom. They utilize previous energy intensity work published by Dutch authors on the agricultural, transportation, and retail stages of food production. Because diets' energy distribution is characterized by a large mean and standard deviation, the authors conclude that GHG emissions could be reduced significantly by shifts in dietary composition.

Vieux et al. (2013) study actual diets of French adults and find that GHG emissions and nutritional quality are positively related. The more nutrient-dense (nutritious, composed of fruit and vegetables) the diet is, the more GHG emissions the diet produces while the more energy-dense (calorie-rich, composed of sweets consumed in excess) the diet is, the lower the GHG emissions. Their finding that a nutritious, plant-based diet is relatively high in GHG emissions is contradictory to other research cited above.

Vieux et al. (2013) emphasize how dramatically consumers would have to change their diets to marginally reduce emissions. For example, only 5 percent of Americans considered themselves vegetarian in 2012 according to a Gallup poll, down from 6 percent reported in both 1999 and 2001 (Newport, 2012). Two percent self-report as vegans. Other articles also report marginal effects of dietary change. Wallen, Brandt, and Wennersten (2004) report that even if the entire Swedish population adopted the sustainable diet they evaluate, "energy use [from the cultivation and distribution stages] would not decrease and the emission of carbon dioxide equivalents would only decrease by 5 percent" (p. 529). The sustainable diet includes animal-based products, but with reduced levels of meat, cream, and cheese than the current Swedish diet. A Finnish article studying both local foods and production methods (organic versus conventional) finds the differences in emissions between the mixed diets are negligible. However, some GHG emissions (CO_2, N_2O, and CH_4, measured in CO_2-equivalents) could be reduced with a vegetarian diet, keeping the energy intake constant with the mixed diet levels (Risku-Norja, Hietala, Virtanen, Ketomaki, & Helenius, 2008).

Other researchers advise that in addition to shifting dietary composition, a decrease in consumption would be more sustainable. As Gussow points out, "To over-consume calories is to waste food" (Gussow & Clancy, 1986, p. 3). Pimentel et al. (2008) recommend reducing the then-current U.S. consumption by over 1,000 calories. Major cuts include a 65 percent reduction in the sweeteners and the fats and oils categories, a 50 percent reduction in meat and fish categories and a 40 percent decrease in eggs (Pimentel et al., 2008). McMichael and Butler (2010) advocate a limit of 90 grams of meat per day, with 50 grams or less from ruminant animals as a sustainability threshold.

Therefore, there are many studies that evaluate the extent to which diet contributes to GHG emissions and thus, climate change, with a particular focus on livestock production. Understanding the environmental effects is important as meat consumption continues to climb worldwide and as climate change remains a persistent concern. There are inconsistencies in the findings because of the varying methods (i.e. stages of life included in the LCA) and what is being measured (i.e. single products, hypothetical diets, actual diets). Therefore, the link between food consumption decisions and GHG emissions is an interesting and unresolved research topic, especially in connection with sustainability.

2.2 Methods and Results

2.2.1 Diet Decomposition

This work extends Eshel and Martin's (2006) study of CO_2 emissions by considering diets representative of actual consumption patterns. I use a scenario analysis methodology which is described below.

First, I identify healthy diets worldwide (Duchin, 2005; Adamsson et al., 2010; Renaud & de Lorgeril, 1992). The necessity of evaluating nutritious diets in addition to their energy efficiency is emphasized by Carlsson-Kanyama (1998). Selected diets include the French, Japanese, Mediterranean, Nordic, and U.S. diets. The countries selected to represent these diets are France, Japan, Greece, Finland, and the United States, respectively. I use data retrieved from the FAO Food Balance Sheets, which provide food supply data. FAO food supply data are often used as a proxy for consumption in diet-related studies at the country level. Examples include Eshel and Martin (2006) and the U.S. Department of Agriculture's Economic Research Service (2013) for the United States; and Tukker et al. (2011) for the European Union.

Secondly, the diets are decomposed into their animal-based and plant-based components as shown in Figure 2.1 since the literature emphasizes the variation in energy inputs between animal-based and plant-based foods.

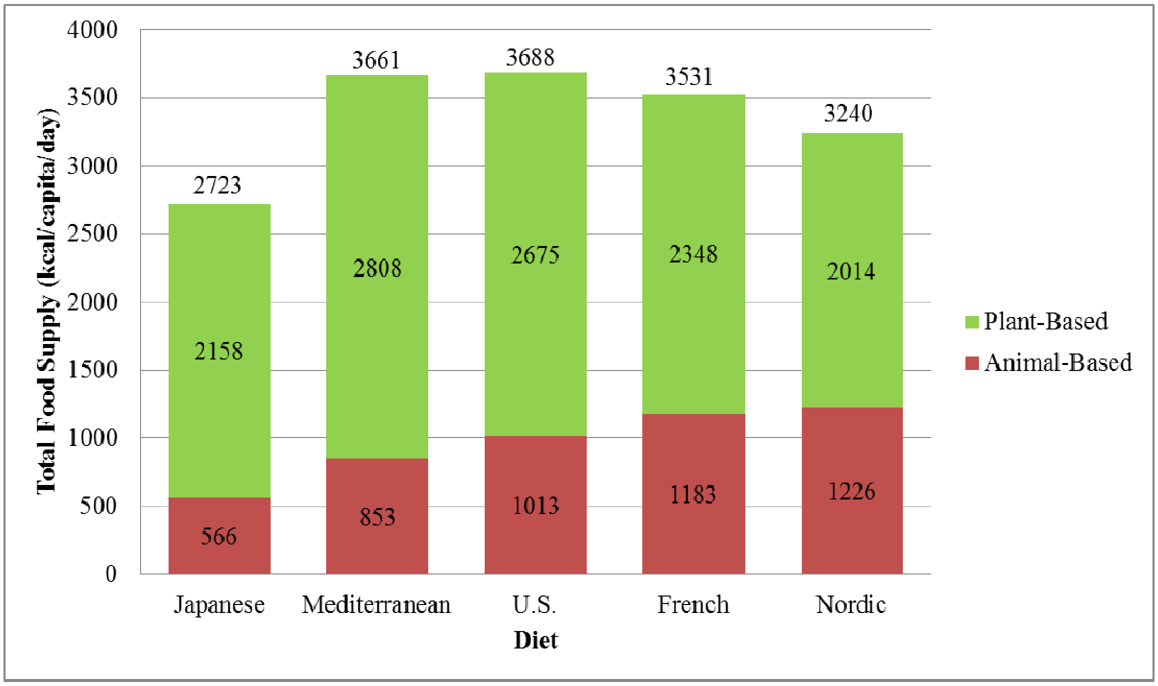

Figure 2.1. Decomposition of Diets into Their Animal-Based and Plant-Based Proportions Shown in Kcal.
Note. Data are from FAO (2013b). Legend and bars are organized in the same order.

Figure 2.1 shows the composition of diets. The red areas show the amount of kilocalories (kcal)[5] consumed that came from animals and in green, those that came from plants. The total amount of kcal consumed is shown at the top of each bar. Figure 2.1 indicates the United States is consuming the most kcal per capita per day, but similar amounts are consumed in the Mediterranean and French diets. In the Nordic diet, 448 fewer kcal per capita per day are consumed while the Japanese have a caloric intake of 965 fewer kcal per capita per day.

[5] "When the term calorie is used to express amount of energy provided by food or expended during body activities, the term kcalorie or large Calorie is actually meant" (FAO, 2013a). 1 kilocalorie = 1000 calories = 4184 Joules.

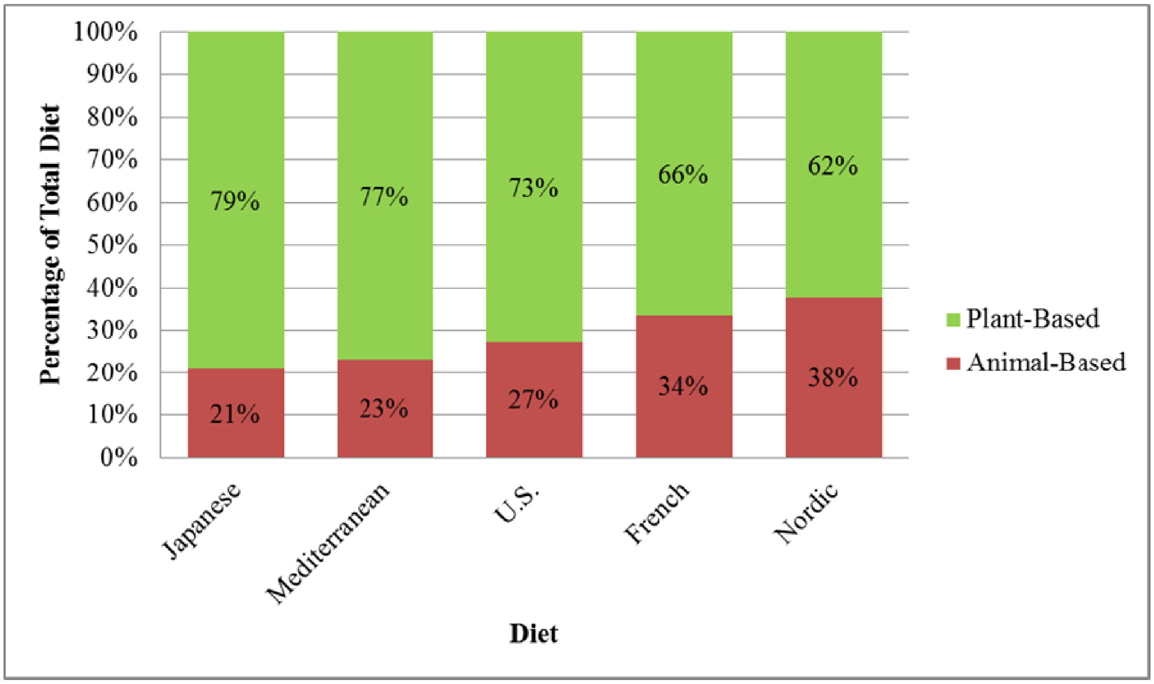

Figure 2.2. Decomposition of Diets into Their Animal-Based and Plant-Based Proportions.
Note. Data are from FAO (2013b). Legend and bars are organized in the same order.

In Figure 2.2, the kcal attributed to animal or plant-based portions are shown as a percentage of total kcal. The diets are arranged so that the animal-based percentages are increasing incrementally from the left to the right along the x-axis. Figure 2.2 shows that the Japanese have the lowest percentage of animal-based products in their diet whereas the Nordic diet has the highest percentage.

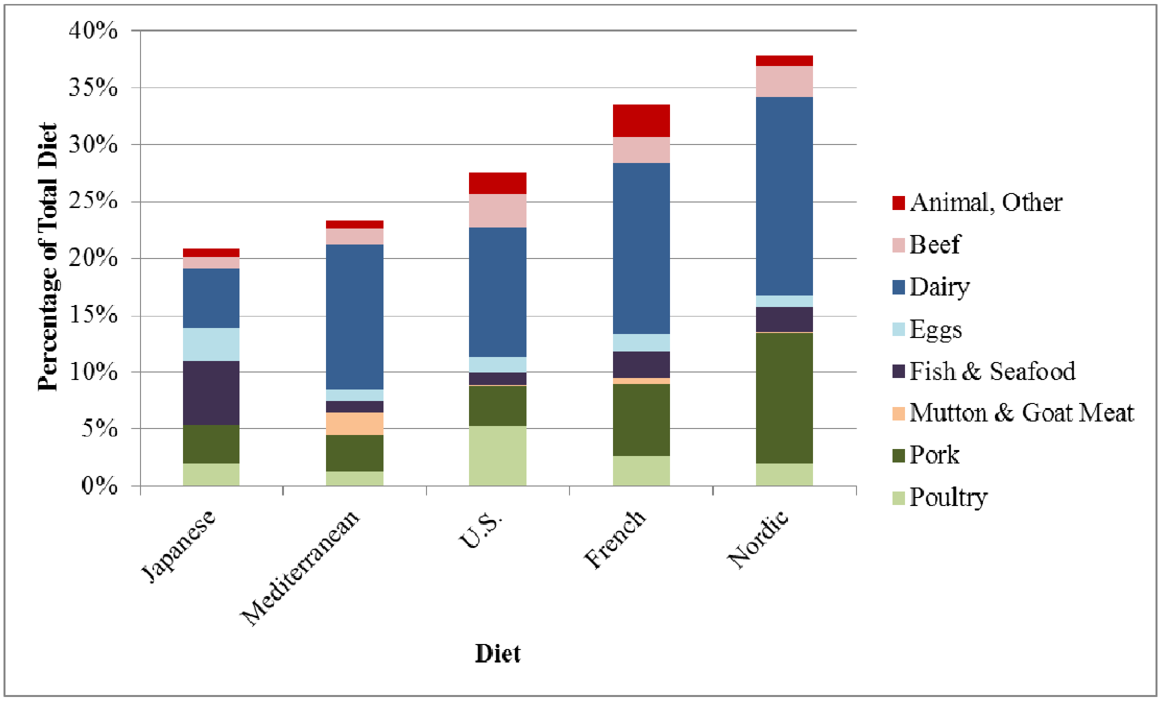

Figure 2.3. Decomposition of the Animal-Based Proportion of the Diets.
Note. Data are from FAO (2013b). Legend and bars are organized in the same order.

Figure 2.3 shows a further decomposition of the animal-based portion of the diet into different types of animal-based products. For example, mutton and goat meat are consumed in Mediterranean and French diets while in the U.S., Japanese and Nordic diets, mutton and goat meat either is not consumed or the amount is negligible. Pork makes up the largest percentage of the meats in the Nordic, Mediterranean, and French diets whereas poultry is most often consumed in the United States. Although the Japanese eat a small amount of dairy products comparatively, their diet consists of 6 percent fish and seafood and 3 percent eggs. The Nordic diet is made up of the most amount of dairy products, 17 percent of the total diet.

2.2.2 Energy Efficiency Calculations

The energy efficiencies for the dietary components are calculated using Pimentel and Pimentel (2008) data, which is supplemented with the USDA National Nutrient Database for Standard Reference, Release 26 (2013b) for the animal products. Energy efficiencies for animal-based products are calculated by multiplying $\frac{kcal\ protein}{kcal\ input}$ by $\frac{kcal\ total}{kcal\ protein}$ to obtain the ratio $\frac{output\ energy}{input\ energy}$. Energy efficiencies for plant-based products are reported by Pimentel and Pimentel (2008) in the $\frac{output\ energy}{input\ energy}$ ratio, so no additional calculation was necessary. These energy efficiencies are based on U.S. conventional production. Although the representative diets are international, the goal of this research is to measure the associated costs of dietary changes in the United States.

The individual energy efficiencies of some common food products are reported in the last column of Appendix Table A.1. The relative energy inefficiency of animal-products are due to the higher grain and forage inputs and additional fossil energy inputs required to produce animal protein. In addition to the direct feed costs, there are the indirect costs of maintaining the breeding animals in livestock production (Pimentel & Pimentel, 2008). "The major fossil energy inputs for grain and forage fed to animals include fertilizers, farm machinery, fuel, irrigation, and pesticides" (Pimentel, 2006, p. 21).

As indicated in Appendix Table A.1, there is variation in the energy efficiencies of different products. For example, oats are the most efficient crop since for every one kcal of input energy, 5.10 kcal of output energy is produced. Least efficient is lobster production, in which one kcal of input energy produces 0.0057 kcal of output energy, rounded to 0.01 in Appendix Table A.1. A ranking of efficiencies for animal products are shown in Table 2.2 below from most efficient to least efficient.

Table 2.2

Ranked Energy Efficiencies of Animal Products

Animal Product	**Calculated Efficiency[a]**
Poultry	0.42
Dairy	0.32
Pork	0.26
Fish and Seafood	0.18
Beef cattle	0.09
Lamb	0.07
Eggs	0.07

[a] Energy efficiency is the ratio of kcal output per kcal input. Therefore, the higher the value, the more efficient the product is.

2.2.3 Dietary Energy Composition

Using the U.S. energy efficiencies for each animal product, a weighted mean of the animal-based portion for each of the diets is calculated, shown in Appendix Table A.2. For example, in the United States, beef makes up 3 percent of the kcal in the total diet, yet makes up 11 percent of the animal-based portion. The calculated efficiency of the animal-based portion of the U.S. diet, shown in the last column of the table, is 0.28. This means that, on average, for every 100 units of energy input in production, 28 units of output, measured in kcal, is produced for the mix of animal-products consumed in the United States. Interestingly, the U.S. diet is the most efficient in terms of animal-based composition of consumption, not adjusted for total kcal consumed. This is because 73 percent of the animal-based portion is made up of dairy, poultry, and pork which are the most efficiently produced animal products. Notably, the United States is still consuming the highest proportion of beef. The Japanese diet is the least efficient diet in terms of animal-based composition because fish and seafood make up 27 percent of their animal-based portion which is relatively energy inefficient category. Also, eggs, which are the least efficient animal product, make up 13 percent of their animal-based proportion.

2.2.4 GHG Emissions

To quantify the GHG emissions associated with the diets considered in this research, the following formula from the Eshel and Martin (2006) paper is used:

$$E_i = cd\left[\frac{\alpha_i}{e_i} + \frac{(1-\alpha_i)}{f}\right] \quad (1)$$

where $i = \{French, Japanese, Mediterranean, Nordic, U.S.\}$. E_i represents the emissions associated with each diet, while *c* measures the kcal per capita per year consumed in the United States, and *d* is the conversion rate between tons of CO_2 per BTU. Therefore, *cd* represents the tons of CO_2 emitted per capita per year. Inside the brackets, α_i is the proportion of animal-based products in the diet divided by e_i, the energy efficiency of the animal-based portion of the diet. Therefore, (1- α_i) is the proportion of plant-based products in the diet, which is divided by *f*, the energy efficiency of plant production. The total diet efficiency is represented by $\left[\frac{\alpha_i}{e_i} + \frac{(1-\alpha_i)}{f}\right]$.

The value calculated for e_i is reported in the last column of Appendix Table A.2. The energy efficiencies of plant-based products for human consumption in Appendix Table A.1 are averaged resulting in 1.84 which I round to 2. Eshel and Martin (2006) also use 2 based on the possible range of energy efficiencies for plant foods calculated by Pimentel and Pimentel (1996). Additionally, the FAO data on vegetable products are not broken down into as specific categories as animal products preventing a more accurate decomposition of plant-based products in the diets. Therefore, setting $f = 2$ reflects a reasonable estimation of the energy efficiency and means that for every one unit of energy input measured in kcal, two units of output are produced. With the energy efficiencies in the denominator of Equation 1, it is clear that there is an inverse relationship between efficiency and emissions.

The bracketed term, as a whole, represents each diet's efficiency, including both the animal and plant-based portions. The diet efficiencies are ranked below in Table 2.3 which shows the Mediterranean diet is the most efficient.

Table 2.3

Total Diet Efficiency

Diet	**Calculated Diet Efficiency**[a]
Mediterranean	1.26
Japanese	1.28
U.S.	1.34
French	1.58
Nordic	1.69

[a] This is the bracketed term in Equation 1. Diets are ranked from most efficient to least.

In this research, two scenarios are considered. The first scenario aims to further examine shifts in dietary composition. Therefore, the amount of kcal consumed is held constant across each diet at the U.S. consumption level of 3,688 kcal per person per day, or 1,346,120 per year, in 2009. Other studies using scenario analysis have done this for consistency in comparison (Eshel & Martin, 2006; Saxe, Larsen, & Mogensen, 2013; Tukker et al., 2011).

To establish the relationship between tons of CO_2 and BTUs, 2009 data from the U.S. Department of Energy's Energy Information Administration (EIA) is used by dividing total CO_2 emissions from energy consumed (5,435.279 million metric tons) by BTUs of energy consumed (94.559 quadrillion), which equals $5.74803 \times 10^{-8} \frac{ton\ CO_2}{BTU}$. Then, *d* is calculated using the above conversion rate, which yields tons of CO_2 per kcal by multiplying $5.7 \times 10^{-8}\ \frac{ton\ CO_2}{BTU}$ by the energy conversion factor of 1 BTU per 0.25 kcal, which equals $2.28\ \times\ 10^{-7}\ \frac{ton\ CO_2}{kcal}$. Using this exact method in their paper, but older data, Eshel and Martin (2006) calculate $d = 2.778 \times 10^{-7} \frac{ton\ CO_2}{kcal}$. When multiplied together, $cd \approx 0.3$ which equals the tons of CO_2 emitted per capita per year.

Therefore, E_i represents the tons of CO_2 emitted per capita per year attributable to food consumption. The bracketed term as a whole is what changes in Equation 1 when calculating the emissions since it represents the energy efficiency of the different diets, where *cd* and *f* are held constant.

Table 2.4

Results for Scenario 1: Shift in Dietary Composition, Total Kcal Constant at U.S. Level

Diet	**Tons of CO_2***	**Driving Miles***	**Ton of CO_2 Relative to the U.S. Diet***	**Driving Miles Relative to the U.S. Diet***	**Change in Tons of CO_2 per Year in the United States**	**Percentage Difference**
Japanese	0.394	931	-0.017	-39	-5,126,300	-4.06%
Mediterranean	0.388	917	-0.023	-53	-6,961,226	-5.51%
U.S.	0.410	970				
French	0.484	1,144	0.073	174	22,586,012	17.89%
Nordic	0.518	1,225	0.108	254	33,118,376	26.23%

* Per capita per year

As shown in Table 2.4, the Mediterranean diet has the lowest level of annual emissions at 0.388 tons of CO_2 per capita, yet the Mediterranean diet is characterized by 23 percent animal-based products, compared to 21 percent in the Japanese diet. Therefore, the emissions associated with one's diet cannot be determined only from the animal-based proportion, but the mix of animal products must be considered. Still, the Nordic diet has the highest emissions level compared to the other diets and also had the highest proportion of animal-based products.

Emissions are translated into driving miles, a common metric which helps contextualize emissions, in columns three and five in Table 2.4., using the EPA's calculated average of 423 grams of tailpipe CO_2 emitted from driving one mile (U.S. Environmental Protection Agency, Office of Transportation and Air Quality, 2011). After converting grams of CO_2 to metric tons, E_i is divided by 0.000423. As shown in Table 2.4, consuming the average U.S. diet is equivalent to driving 970 miles annually in terms of CO_2 emissions.

Extrapolating the per capita calculations, the total CO_2 emitted in the United States due to food consumption was approximately 126 million metric tons in 2009. The sixth column in Table 2.4 shows the change in emissions if the entire U.S. population in 2009 adopted an alternative diet. By altering dietary composition to match a Mediterranean-type diet, emissions decrease by approximately 7 million tons annually. Alternatively, by altering dietary composition to match the Nordic diet, 33 million more tons of CO_2 are emitted per year. The last column shows the difference in emissions between the U.S. and alternative diets in percentage terms.

2.2.5 GHG Emissions Extended

The second scenario of interest allows both dietary composition and total kcal to shift, consistent with the total kcal supply in each country as reported by FAO (2013b). Recall that c represents the amount of kcal per capita per year in Equation 1; therefore c is now allowed to vary. Table 2.5 shows the new values for cd.

Table 2.5

Tons of CO_2 per Capita per Year Based on Respective Total Kcal

Diet	$\boldsymbol{c_i \times d}$
Japanese	0.23
Mediterranean	0.30
U.S.	0.31
French	0.29
Nordic	0.27

Table 2.6 shows the results for Scenario 2. The first numeric column represents the tons of CO_2 emitted per capita per year, when the *cd* values from Table 2.5 are used in Equation 1. For the United States, the calculated emissions are the same at 0.41 tons. As seen in Table 2.6, by consuming the Japanese diet and decreasing caloric intake to their level of 2,723 kcal per capita per day, CO_2 emissions could be reduced by 29 percent.

Table 2.6

Results for Scenario 2: Shift in Both Dietary Composition and Total Kcal

Diet	**Tons of CO_2***	**Driving Miles***	**Ton of CO_2 Relative to the U.S. Diet***	**Driving Miles Relative to the U.S. Diet***	**Change in Tons of CO_2 per Year in the United States**	**Percentage Difference**
Japanese	0.291	687	-0.120	-283	-36,820,483	-29.16%
Mediterranean	0.385	910	-0.025	-60	-7,834,573	-6.21%
U.S.	0.410	970				
French	0.463	1,095	0.053	125	16,249,822	12.87%
Nordic	0.455	1,076	0.045	106	13,758,619	10.90%

* Per capita per year

Comparing the emissions associated with the average U.S. diet to the total amount of CO_2 emissions from all sources in 2009, diet represents only 2.3 percent. This percentage is calculated by dividing the 126,353,913 metric tons of CO_2 emitted in the

United States due to diets by 5,435,279,000, the total CO_2 emitted in the United States measured in metric tons.

As noted in the literature review, GHGs emitted by the agricultural sector are estimated by the EPA to be 9 percent. The 2.3 percentage calculated indicates that the remaining CO_2 from agriculture is emitted at other stages of the life-cycle after production or that other GHGs are important to consider.

2.3 Conclusions

In light of the preceding calculations, it is clear that dietary shifts can be a means to mitigate CO_2 emissions. By continuing to consume 3,688 kcal per day, but shifting to a Mediterranean-type diet, one could reduce their CO_2 impact by 5.5 percent. Alternatively, by choosing a Nordic-type diet, one would increase their impact by 26 percent.

CO_2 reduction will be more substantial if consumption is reduced. The analysis shows that the CO_2 emissions attributed to the four alternative diets decrease when consuming their respective total kcal amount, all less that the U.S. total kcal level. For example, when total kcal is taken into account, emissions embedded in the Nordic diet decreases from 0.52 to 0.46 metric tons per capita per year. The Japanese dietary emissions decrease from 0.39 to 0.29 metric tons per capita per year. The results show that the proportion of animal-based foods consumed does not have a continuously positive relationship with emissions. The energy efficiency of the diet and subsequent emissions are dependent on the mix of animal-based food that is being consumed, not necessarily the percentage of animal products in the diet. All of the diets looked at are representative diets, consisting of a mix between animal and plant-based products. A larger change in CO_2 emissions may be observed if one switched to a completely plant-based diet. While to stop eating meat or animal-based products altogether are both unlikely, a shift in diet is possible.

The varying efficiencies between different animal-based or plant-based foods are relevant. For example, the production of chicken is more than ten times more efficient than lamb when eating an equivalent amount of kcal from protein (Table 2.1).

It is important to consider how this research can be expanded to include other stages of the life-cycle of food. This research looks at the production stage, but the other stages such as transportation, storage, or at-home preparation could be included to make the emissions estimates more complete.

Non-CO_2 GHGs at the farm-level could also be added to the analysis such as methane (CH_4) or nitrous oxide (N_2O), both with higher GWP than CO_2. Additionally, other resources involved in the production should be considered such as water and land use change. Also, biodiversity may be a metric to consider when sustainability is being evaluated (Vieux et al., 2013).

CHAPTER 3: DIET AND HEALTH

The aim of this chapter is to use regression analysis to a) establish a link between a country's diet and the health status of its population and b) use the regression results to measure how a shift in the U.S. diet to the other diets would affect U.S. BMI. For data, I use pooled cross-section time-series data from the United States and the four countries representing the four diets discussed in Chapter 2, namely Finland, France, Greece, and Japan. Selection and measurement of the dependent and independent variables to include in the regression model is guided by the literature, which I review next.

3.1 Related Literature

3.1.1 Defining and Measuring Weight Status

BMI is a metric used to identify and classify one's weight. Although not a perfect tool – since BMI cannot distinguish between mass from muscle versus fat – it is widely used because of its accessibility. It is calculated by dividing weight (in kilograms) by height (in m^2) (World Health Organization, 2014a). Other methods that could be used, but that require specialized equipment or facilities, include skinfold thickness measurements, underwater weighing, bioelectrical impedance, dual-energy x-ray absorptiometry (DXA), or isotope dilution (Centers for Disease Control and Prevention, 2013).

Table 3.1

Internationally Accepted Body Mass Index Classifications of Weight Status

BMI	**Weight Status**
Below 18.5	Underweight
18.5 – 24.9	Normal
25.0 – 29.9	Overweight
30.0 and Above	Obese

Note. Adapted from *About BMI for Adults*, by the Centers for Disease Control and Prevention, 2013, http://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/index.html.

Table 3.1 shows the internationally accepted BMI classifications. Yet, the Japan Society for the Study of Obesity redefines a BMI of 25 or greater as obese for the Japanese (Kanazawa et al., 2002). Asians generally have more abdominal body fat at lower BMI levels and health risks may be exacerbated by distribution of body fat (Senauer & Gemma, 2006). Obesity is further classified into three types, shown in Table 3.2.

Table 3.2

Internationally Accepted Body Mass Index Classifications of Obesity

Obese	**≥ 30.00**
Obese class I	30.00 – 34.99
Obese class II	35.00 – 39.99
Obese class III	≥ 40.00

Note. Adapted from *BMI classification* by the World Health Organization, 2014a, http://apps.who.int/bmi/index.jsp?introPage=intro_3.html. Copyright 2006 by the World Health Organization.

3.1.2 Rise of Obesity

There exists a global paradox of under-nutrition and over-nutrition, both of which are forms of malnutrition and both of which are preventable diseases. Being overweight is more prevalent today than in the past, growing to 1.4 billion adults worldwide in 2008 (World Health Organization, 2013a). Of these 1.4 billion, 500 million are obese (FAO, 2013c). The 1.4 billion who are overweight have surpassed the 868 million who are undernourished.

Since 1980, obesity rates worldwide have almost doubled (Harvard School of Public Health, 2014). Over-nutrition is prevalent in high-income countries, yet it is also growing in low and middle-income countries (Popkin, Adair, & Ng, 2012), and, according to the World Health Organization (2013a), "it is not uncommon to find under-nutrition and obesity existing side-by-side within the same country, the same community and the same household." Similarly, over-nutrition is not limited to a certain age, race, ethnicity, gender, or socioeconomic group (Finkelstein & Strombotne, 2010; Stein & Colditz, 2004; World Health Organization, 2013a).

The obesity rate more than doubled in the United States during the final four decades of the twentieth century. Table 3.3 shows the results from the National Health and Nutrition Examination Surveys (NHANES). During the earliest period 1959-1962, BMI was 24.9 and 12.7 percent of the population was obese. Since then, there has been an upward trend in both BMI and the percentage obese. In the latest period reported in the table, 1999-2000, BMI was 27.9 and almost 30 percent of the population was obese. The table indicates that the BMI distribution in the United States is changing; either shifting to the right or becoming more skewed towards higher BMI levels in the right hand side of the distribution.

Table 3.3

Trends in Average Body Mass Index and the Percentage Obese, Persons 18 Years of Age and Older

Survey	**Period**	**Body Mass Index**	**Percentage Obese**
NHES I	1959 – 1962	24.91	12.73
NHANES I	1971 – 1975	25.14	13.85
NHANES II	1976 – 1980	25.16	13.95
NHANES III	1988 – 1994	26.40	21.62
NHANES 99	1999 – 2000	27.85	29.57

Note. Adapted from "An economics analysis of adult obesity: Results from the Behavioral Risk Factor Surveillance System" by S.-Y. Chou, M. Grossman, and H. Saffer, 2004, *Journal of Health Economics, 23*, p. 567. Copyright 2004 by Elsevier B.V.

The prevalence of overweight and obesity for each of the countries considered in this research is shown in Table 3.4. In 2010, a total of 69.4 percent of the adult population in the United States was overweight or obese. Of this 69.4 percent, 32.9 percent were overweight and 36.5 percent were classified as obese (OECD, 2013b). The OECD data show that the rates have increased from 47.4 percent of the U.S. population experiencing excess weight in 1978, with 32.4 percent of the population overweight and 15 percent of the population obese.

Table 3.4

Prevalence of Overweight and Obesity

Country	**% of Population Obese or Overweight**	**% of Population Obese**
Japan	25.5	4.1
France	42.9	12.9
Finland	50.8	16.6
Greece	55.7	17.3
United States	69.4	36.5

Note. Data are from OECD (2013b). The most recent year for each country is reported; Japan (2011, measured), Greece (2009, self-reported), United States (2010, measured), France (2010, self-reported), Finland (2011, self-reported).

Finkelstein et al. (2012) forecast an increase in U.S. obesity prevalence through 2030 using individual data from the Behavioral Risk Factor Surveillance System (BRFSS) augmented with state-level data from 1990 to 2008. Using a time trend forecast, the authors estimate 51 percent of the population will be obese and 9 percent will be severely obese within the next sixteen years. Severe obesity is defined by Finkelstein et al. (2012) as a BMI greater or equal to 40. They find similar results using a nonlinear regression model, assuming a logarithmic trend. Results from the nonlinear model suggest that 42 percent of the population will be obese and 11 percent will be severely obese.

The obesity rates among adults, and also among children, have become a public health concern. The current rates and the forecasted growth of obesity underscore the necessity of research attention in this area.

3.1.3 Relationship to Other Diseases

Overweight and obesity are not only health conditions themselves, but risk factors for other non-communicable diseases such as heart disease, hypertension, diabetes, cancer, cerebrovascular disease, gallstones, osteoarthritis as well as a number of other conditions (Stein & Colditz, 2004). In a study by Mokdad, Marks, Stroup, and Gerberding (2004) in which the actual (or underlying) causes of death are evaluated, poor diet and physical inactivity rank second behind smoking with 400,000 or 16 percent of deaths in 2000. Because of the increase in the rates of both overweight and obesity, the authors conclude it is likely that the combination of diet and lack of physical activity will become the leading cause of death in the United States in the future (Mokdad et al., 2004).

Overweight and obesity also affect mortality rates. The OECD (2012) reports that the severely obese die 8 to 10 years earlier than individuals within a normal weight range.

Additionally, the risk of early death increases by approximately 30 percent for each 15 kilograms (33 pounds) gained beyond the normal weight range.

3.1.4 The Causes of Obesity

In the most simplistic terms, overweight or obesity can be attributed to an energy imbalance due to an increase in energy consumption (caloric intake), a decrease in energy expenditure (physical activity) or a combination of both. However, the causes of obesity are complex and interrelated, and are influenced by access to healthy foods, opportunities for physical activity, and cultural attitudes towards food consumption, among other environmental variables and genetics.

Obesity has received attention by economists who view the epidemic as an economic problem (Drewnowski, Hanks, & Smith, 2010; Philipson & Posner, 2008). Economic incentives affect health-related decisions. The literature reviewed focuses predominantly on the underlying forces and variables that have created an obesogenic, or obesity-promoting, environment and, thus, an increased proportion of the population who are overweight or obese. In the cited literature below, it will be evident that uncertainty still exists in explaining the prevalence of overweight and obesity.

Much of the research has focused on the United States and has utilized micro-level data sources including BRFSS, NHANES and the Framingham Heart Study. Additionally, Dubois, Griffith, and Nevo (2013) compare household data across countries and others use aggregate country-level data to study obesity including De Vogli, Kouvonen, and Gimeno (2011), Loureiro and Nayga (2005), and Mazzocchi and Traill (2011).

3.1.4.1 Biological

Rosin (2008) cites research connecting obesity and genetics in her complete review of the obesity literature in economics and other fields. Heredity influences a person's weight and one may have a genetic pre-disposition to be overweight passed down from his or her parents. However, the dramatic increase in obesity rates over the entire population is unlikely to be explained by genetics. Rodgers and Collins (2012) report that the gene pool has remained essentially constant over the last few decades while obesity rates have increased dramatically in the United States. The prevalence of obesity is more likely explained by social, behavioral, and environmental influences (Christakis & Fowler, 2007; Stein & Colditz, 2004). Rosin (2008) suggests humans have not been able to adapt as quickly to the environment and, therefore, there may be a biological basis for overconsumption driven by survival instincts.

3.1.4.2 Urbanization

While energy expenditure is an important predictor of weight status, it is difficult to track, so these data are largely unavailable. Instead, one might consider the changes that have influenced daily physical activity. For example, the world population is transitioning from rural areas to urban areas. Concurrent with urban population growth is the transition from an agrarian society to one whose economy (and, therefore, jobs) is dominated by mass industry, technology, and service (World Health Organization, 2014b). Urban population numbers are used as a reasonable proxy for physical activity. However, empirical studies find mixed results on the relationship between urbanization and weight status.

In their study, Mazzocchi and Traill (2011) use panel data for OECD countries and an urban population variable which is assumed exogenous in their obesity equation. Urban population is a proxy for exercise. The authors recognize that urban employment and transportation lead to a more sedentary lifestyle compared to those in rural areas. Also focusing on OECD countries, Loureiro and Nayga (2005) find a negative relationship between percentage of the population living in rural areas and BMI. Ewing, Meakins, Hamidi, and Nelson (2014) study urban sprawl and find lower BMI and obesity rates in more compact areas. This work updates the widely-cited Ewing et al. (2003) paper on urban sprawl by creating new sprawl indices.

Senauer and Gemma (2006) compare Japan and the United States and find that owning and operating a car is much more expensive in Japan. The time cost of driving is much higher as well because of Japan's densely populated urban areas. This may help explain why the Japanese walk more often in their daily lives. By incorporating exercise into their daily routine, the urban Japanese are expending energy, which is likely to lead to a lower BMI. The increased physical activity in dense areas is consistent with the discussion of active travel[6] in the Ewing et al. (2014) paper.

3.1.4.3 Technological Change

Technological advances are at the core of an obesogenic environment as they have has reduced the amount of physical activity required in daily life. This is explored in a paper by Lakdawalla and Phillipson (2002) using U.S. microdata. Their results indicate that the long-run growth of obesity can be attributed to technological change, on the demand side due to declining physical activity both at work and at home and on the

[6] Active travel refers to physical activity such as walking to get from one place to another.

supply side due to agricultural innovation and lowered food prices. By decomposing the growth of weight gain, the authors attribute 40 percent to food supply expansion while 60 percent of the growth is attributed to demand factors. Finkelstein and Strombotne (2010) also note that today's work environment is less physically demanding due to technology.

Leisure time has also become more sedentary. Technology has increased screen time, defined as time spent in front of a television (TV) set or computer monitor. While watching TV, one is not expending a substantial amount of calories and it is an activity linked to snacking (Gore, Foster, DiLillo, Kirk, & Smith West, 2003). Additionally, one may be exposed to food advertising, which has been implicated in increased caloric intake and BMI, especially for children (Boulos, Kuross Vikre, Oppenheimer, Chang, & Kanarek, 2012; Chou, Rahad, & Grossman, 2005; Harris, Bargh, & Brownell, 2009). In a recently published experimental study involving a sample of 186 adults, Rusmevichientong, Streletskaya, Amatyakul, and Kaiser (2014) explore the effects of healthy food, anti-obesity, unhealthy food, and mixed food advertising on food consumption choices and caloric intake. The researchers do not find a statistically significant correlation between unhealthy food advertising and caloric intake using a differences-in-differences (DID) model. Then, using an ordered probit model, they find that unhealthy food advertising does not significantly affect food purchasing decisions either.

In the United States, those with access to the internet increased from 1 percent to 45.6 percent between 1990 and 2000, then increased to 68.8 percent in 2008 (Finkelstein et al., 2012). Finkelstein et al. (2012) use an internet access variable in their projections of obesity rates in 2030 and find that internet access is positively associated with the probability of being obese. De Vogli et al. (2011) find the percentage of internet users in OECD countries to be a significant variable in modeling obesity prevalence.

3.1.4.4 Prices and Income

Finkelstein and Strombotne (2010) report that the price of food (especially high-calorie food) has continued to decrease due to technological advancements, especially in food processing, and farm subsidies for corn and soybeans. Since 1978, food prices have declined 38 percent compared to price changes of other goods and services. The positive impact of decreasing prices of food on obesity rates is supported by Rashad and Grossman (2004).

Finkelstein et al. (2012) explore the relationship between prices and obesity prevalence in their work forecasting future obesity rates in the United States. They use prices for alcohol, gas, and fast food and relative prices including prices of groceries relative to non-grocery items and prices of healthier foods relative to less-healthy foods in their model. They find that their price index of groceries relative to non-grocery items decreased from 1990 to 2000 and then increased from 2000 to 2008. The index in 2008 was still lower than in 1990. This indicates that groceries have become relatively inexpensive. The price of a fast food meal and the price index of healthier food relative to less-healthy food remained essentially the same between 1990 and 2008. The healthier food prices relative to less-healthy food prices is statistically significant in the regression and indicates that when healthier food becomes relatively more expensive, the likelihood that the population will be obese increases.

Chou et al. (2004) examine the factors associated with BMI and obesity. They use U.S. cross-sectional data from the BRFSS between the years 1984-1999. Regression variables include prices of fast-food restaurants, full-service restaurants, food at home, cigarettes, and alcohol. The prices of three fast-food restaurant items from the American Chamber of Commerce Research Association (ACCRA) Cost of Living Index are averaged and then deflated by the Bureau of Labor Statistics Consumer Price Index (CPI). The full-service restaurant price is the average cost of a meal as reported by the Census of Retail Trade. They find negative signs on the food prices and positive signs on the cigarette and alcohol prices in both regressions; in one, BMI is the dependent variable and a dichotomous variable for obesity is the dependent variable in the other regression. In the same article, Chou et al. (2004) find that household income is highly significant and negative in both regressions.

Drewnowki and Spector (2004) show that the lowest-income groups have disproportionately high rates of obesity, as do groups with the least education. Of course, education and income levels are strongly correlated.

There are differences in income effects within and across countries. Lakdawalla and Philipson (2002) find that "empirically, within developed countries, there can be a non-monotonic relationship between income and weight" while across countries "income tends to be correlated with higher weights" (p. 8). Loureiro and Nayga (2005) use per capita gross domestic product (GDP) as an income variable in an inter-country analysis; they find it to be significantly and positively correlated with BMI.

Drewnowski and Darmon (2005) consider energy and nutrient density of foods. Energy density is defined as the energy per unit of weight or volume of food. Examples of energy-dense foods include refined grains, added sugars, and added fats. Conversely, examples of nutrient-dense foods include lean meats, fish, fresh vegetables, and fruit.

Using data on energy cost per unit, Drewnowski, Hanks, and Smith (2010) find an inverse relationship between energy density and energy cost. The authors suggest that energy-dense foods have Giffen-good[7] characteristics, meaning that, unlike normal goods, their consumption increases as their prices increases.

3.1.4.5 Total Economic Costs

Cutler, Glaeser, and Shapiro (2003) present a theory in which the time cost of food has decreased, allowing for more frequent and varied food consumption and leading to higher weights. This theory is consistent with demand theory when cost is inclusive of both time and monetary costs; as total cost decreases, demand (for food) increases. The authors invalidate other commonly held theories as to why there has been a fundamental shift in obesity rates since 1980 including increased portion sizes, fast food meals, substantial changes in energy expenditure (both voluntary and involuntary), and television watching.

The data support the four empirical implications of their theory. Their first test on changes in food type, consumption, and time reflects that snacks, rather than increased caloric intake during meals, have increased total caloric intake. The increase in median weight can be explained by overconsumption of just 100 to 150 calories per day, the calories in three Oreo cookies or a can of Pepsi, as shown by their equation. Secondly, by evaluating calories for different food products, they find a statistically significant and positive correlation between commercial processing and percent change in calorie consumption. The degree of commercial processing is measured by farm value share, calculated by the USDA. Their results mean that consumption of food products that

[7] A Giffen-good defies the law of demand; as price increases, demand for the good also increases.

require the most processing has increased. Thirdly, the obesity rates of married women have increased the most, for whom food costs have fallen the most. For example, in 1965, married women who were not working outside the home spent 137.7 minutes per day on meal preparation and cleanup. This time spent on meal preparation and cleanup fell to 68.8 minutes in 1995. Comparatively, a married male with a nonworking spouse spent 9.4 and 14.4 minutes on meal preparation and cleanup in 1965 and 1995, respectively. They test the change in obesity across demographic groups using regression analysis where change in BMI is the dependent variable. Lastly, also using regression analysis, the authors find that the countries that encourage technological change experience less time cost of food and therefore, higher obesity rates. Variables included in the model that hinder technological change are frequency of price controls, producer protection, number of food statutes, civil law origin, and days it takes to open a business.

Finkelstein and Strombotne (2010) attribute the obesity-promoting environmental changes to economic costs. They conclude that people choose obesity-promoting behaviors, which conform to utility maximization since "it is just too costly (in economic terms) to weigh less" (p. 1522S). First, calorie consumption costs have decreased. As the relative price of food has gone down, the economic costs (in time and energy) of at-home food preparation has also gone down due to technology such as microwaves. Also, out-of-home options such as restaurants and vending machines have become widely available.

Concurrent with lower calorie consumption costs, calorie expenditure costs have increased. Jobs have become less physically demanding and there is a high opportunity cost of exercising during leisure time since screen time via a host of new technologies has become increasingly popular.

Additionally, Finkelstein and Strombotne (2010) suggest that obesity rates have increased due to a lack of the motivation to engage in health-seeking behavior. Insurance is an underlying factor in two ways. First, insurance provides access to technological advancements in medical, pharmacologic, and surgical treatments for the disease at a lower cost. Secondly, insurance may create a moral hazard for becoming or staying obese.

3.1.4.6 Restaurants and Fast Food

In 2012, the average American spent 12.8 percent of his or her income on food, 7.6 percent on food prepared at home and 5.2 percent on food away from home (U.S. Bureau of Labor Statistics, 2013). The data indicate that Americans spend 59 percent of their food expenditures for food at home and the remaining 41 percent on food away from home.

Nielsen and Popkin (2003) confirm that portion sizes in the United States have increased between 1977 and 1998. They study a subgroup of popular food items and find that portion sizes have increased substantially for all items, except for pizza, both at home and away from home. For most of the food items, fast food restaurant portions are the largest when compared to at home or other restaurants portion sizes.

There is research interest in fast food restaurants and their relationship to obesity, yet there is not concrete evidence linking the two. Currie, DellaVigna, Moretti, and Pathania (2010) study the effects of fast food restaurants on students and pregnant women. They utilize large data sets and experiment with several regression model specifications. The authors find that a fast food restaurant within 0.1 miles of the school is linked to an obesity rate at least 5.2 percent higher among ninth graders than if the fast food restaurant is 0.25 miles away. Using data from 1999 to 2007, they calibrate their results by multiplying the share of schools within 0.1 miles of a fast food restaurant by the 1.7 percentage point estimated impact of fast food restaurants within 0.1 miles and then divide that amount by 22 percent, the increase in the obesity rate of ninth graders since 1970. After calibration, they conclude that only a 0.5 percent increase in obesity rates for ninth graders can be attributed to the proximity of fast food restaurants over the past 30 years. For pregnant women, a fast food restaurant within 0.5 miles of their home increases the probability of gaining over 20 kg by 1.6 percent, but increases by 5.5 percent more when the fast food restaurant is within 0.1 miles. Currie et al. (2010) calibrate these results by multiplying the estimated weight gain when residing within 0.5 miles of a fast food restaurant, extrapolated over 10 years, by the proportion of women living within 0.5 miles of the fast food restaurant and then divide that amount by the average increase in weight in this group. After calibration, they find that 2.7 percent of the weight gain among all women under the age of 34 can be attributed to the proximity of fast food restaurants over the past 10 years. Therefore, the authors conclude that the proximity of fast food restaurants is neither a determinant in obesity for students or mothers. Additionally, they find that other restaurants (non-fast food) do not have any effect on weight gain in both the student and pregnant women cases.

De Vogli et al. (2011) look at a cross-sectional study of 26 advanced economies using Subway restaurants as a representative of fast food restaurants. They find a significant correlation between obesity rates and the density of Subway restaurants. The

United States and Canada have some of the highest fast food density and obesity rates while Japan and Norway have some of the lowest in the sample. There is a large range of both Subway restaurant density and obesity prevalence in the data, yet the results must be interpreted cautiously and causality cannot be inferred.

Chou et al. (2004) use regression analysis to examine the factors driving the increase in BMI and obesity rates since the late 1970s. A major result is "the large positive elasticities associated with the per capita number of restaurants and the importance of trends in this variable in explaining the stability of obesity between 1960 and 1978 and the increase since 1978" (p. 32). Although this leads one to believe that restaurants explain the increase in weight, closer inspection indicates that time cost is an underlying factor. Time has become more valuable and, therefore, the time spent away from work is more valuable. Restaurants and fast-food outlets thus provide a way to cut down on at-home preparation of food.

3.1.4.7 Females in Labor Force

Rashad, Grossman, and Chou (2005) note two changes have taken place, which may be changing consumption patterns: a substantial increase in the number of restaurants and the fact that a higher percentage of females are in the labor force. By pooling data from the First, Second, and Third NHANES and augmenting it with state-level data, they find that the number of restaurants per capita increases obesity rates. Females were affected more than males in the regression results. They authors suggest that this may be due to higher time costs, especially for women who are balancing their time between work and home.

Loureiro and Nayga (2005) use data from multiple countries for their regression analysis and find that the number of females in the labor force is significant in explaining the overweight population, but not the obese population. Cutler et al. (2003) reject women in the labor force as a driver of obesity.

3.1.4.8 Smoking

There are two main reasons in which smoking may be linked to obesity. First, smoking and overeating are both unhealthy, risky behaviors. An experiment was conducted by Anderson and Mellor (2008) who find smoking and being overweight or obese, among other health-related behaviors, to be negatively and significantly associated with risk averseness. They also find those who are risk averse are less likely to partake in one of these unhealthy behaviors. Secondly, smokers have a higher metabolism compared to non-smokers and eat less (Chou et al., 2004).

Efforts to reduce smoking including increasing cigarette taxes and implementing aggressive anti-smoking campaigns have resulted in a declining number of smokers. Rashad et al. (2005) use cigarette taxes and cigarette taxes squared as explanatory variables in a study on determinants of BMI. In the regressions where female BMI is the dependent variable and when BMI is pooled for males and females, they find cigarette taxes to be significant with a positive sign, whereas the squared cigarette taxes variable has a negative sign. The quadratic term is added in the regression "to account for the likelihood that an additional value at higher levels will have less of an effect on the dependent variables as that of an additional value at lower levels" (Rashad et al., 2005, p. 7). The magnitude of the negative coefficients is much lower on cigarette taxes squared than the positive coefficients on cigarette taxes. Their results suggest that the increase in obesity rates is an unintended consequence of the efforts to reduce smoking. Rather than smoking, the focus of their paper is the availability of fast food restaurants which they find to have a causal relationship with higher consumption and less activity.

3.1.4.9 Behavior

Cutler et al. (2003) acknowledge lack of self-control as a contributing factor to obesity. Rodgers and Collins (2012) cite $60 billion of annual expenditures on weight-loss products and programs in the United States, while Cummings (2003) reports up to $100 billion is spent each year on dieting in the United States.

Cutler et al. (2003) present a model of self-control since this behavior is not consistent with utility maximization theory. Instead of lower food costs leading to an increase in utility, they model a situation in which lower food prices decrease utility since someone with self-control problems would be tempted to over-consume. Mann (2008) presents both rational and non-rational explanations for obesity, one of which is akrasia, the lack of willpower. Other research focusing on behavior explores the addictive nature of food, leading to overconsumption.

3.1.4.10 Culture

Dietary traditions differ between the different countries. To use the Japanese diet as an example, value is placed on visual presentation of the food indicated by the Japanese saying “we eat with our eyes” (Senauer & Gemma, 2006). Additionally, restraint is valued, which is indicated by another saying “eat until you’re 80 percent full” (Wilcox, Wilcox, Todoriki, Curb, & Suzuki, 2006). Rather than dinner being the main meal as in the United States, lunch is the main meal in the Mediterranean region.

3.1.4.11 Social Groups

Christakis and Fowler (2007) find that obesity spreads over social networks using data from the Framingham Heart Study. Their results show that if a friend, sibling, or spouse becomes obese, your probability of becoming obese increases by 57 percent, 40 percent, or 37 percent, respectively. The authors reason that an association with an obese person may increase one's tolerance of obesity, influence one's own behavior, or cause physiological imitation. Christakis and Fowler (2007) propose that "even infectious causes of obesity are conceivable" (p. 371). The results are reexamined by Cohen-Cole and Fletcher (2008) who find that social ties are statistically insignificant and, rather, environmental or contextual effects are likely associated to growing obesity rates. Philipson and Posner (2008) note in their paper that "when obesity is relatively rare, it is considered abnormal and repulsive, and this negative response helps to keep it in check" (p. 3).

3.1.4.12 Education and Information

Using micro-level data, researchers have considered how education levels affect obesity rates. In a multi-country study, Sassi, Devaux, Church, Cecchini, and Borgonovi (2009) find a significant and negative correlation between obesity and educational levels. Looking at education a bit differently, Loureiro and Nayga (2005) employ an education expenditures variable when running two regressions. In the first, the dependent variable is percentage of the population that is overweight and obese (BMI > 25). The dependent variable is the percentage of the population that is obese (BMI > 30) in the second regression. They find education expenditures to be negatively associated with BMI in both cases, but only significant when percentage of the population that is obese is regressed on the explanatory variables.

Public awareness of obesity has been increasing. There are highly visible initiatives such as First Lady Michelle Obama's Let's Move program aimed at reducing childhood obesity. Additionally, more information is available about the content of food products since the 1990 mandate and 1994 enforcement of NLEA, though Variyam and Cawley (2008) report that the nutrition-labeling program has not been effective in lowering the levels of obesity.

3.1.4.13 Summary

While previous research has identified and measured the effect of key factors on obesity worldwide, it is difficult to draw a general conclusion because of inconsistent results. Hence, questions remain about the extent to which the various factors influence obesity rates. Since I am interested in the link between diet and BMI across different countries, my research is similar to the work of Loureiro and Nayga (2005) and Mazzocchi and Traill (2011) who also utilize OECD data and some of the same variables. However, I build on their work by decomposing the total kcal consumed in each country into product categories to better understand the effects of consumption choices on BMI.

3.2 Model

3.2.1 Data Set Development and Variables

Examining the same countries studied in Chapter 2, I use cross-section time-series data for the analysis. The dependent variable in the model is BMI. I use age-standardized estimates of BMI for ages twenty and older pulled from WHO (2013b). The data are reported separately for males and females, so a simple average is calculated to get the average BMI for each country in each year over the entire population.

The explanatory variables for BMI include dietary variables and socio-economic variables shown in Table 3.5. There are 9 dietary variables, each representing per capita kcal consumption per day from nine sources: plants, dairy, fish and seafood, other animals, eggs, poultry, pork, mutton and goat, and beef. These product categories are consistent with those used in Chapter 2. The socio-economic variables are annual per capita GDP, degree of urbanization, the consumer price index for food, internet users per hundred people, hours worked per person per week, and grams of tobacco smoked per person per year. The variables chosen are based on the literature reviewed in the previous subsections and available data. Statistics for the variables are reported in Appendix Table A.3. Dummy variables are added to capture cultural differences within the countries. The United States is the base country. Additionally, dummy variables are included to account for variation among the years where 2009 is the base year. The period of analysis is 1980-2009 for 150 observations total among the five countries.

Table 3.5

Regression Variables

Variable	Unit	Definition	Data Source
BMI	kg/(meters squared)		WHO
PLANTS	kcal per person per day	All plant-based products	FAO
DAIRY	kcal per person per day	Composite of butter, ghee, cream and milk	FAO
FISHSEAFOOD	kcal per person per day	Composite of fish, seafood, fish liver oil and fish body oil	FAO
OTHERANIMAL	kcal per person per day	Composite of offal, raw animal fat and other animal meat	FAO
EGGS	kcal per person per day		FAO
POULTRY	kcal per person per day		FAO
PORK	kcal per person per day		FAO
MUTTONGOAT	kcal per person per day		FAO
BEEF	kcal per person per day		FAO
RGDPK	Annual per capita GDP in constant 2005 U.S. dollars		Work Bank Database
URBAN	Percentage of the population living in an urban area		Work Bank Database
CPIFOOD	U.S. dollars, 2010 = 100	Proxy for food prices	OECD
INTERNET	Internet users per 100 people	Proxy for screen time	Work Bank Database
HRSWORKED	Hours worked per person per week		OECD
QSMOKE	Grams of tobacco smoked per capita per year		OECD

3.2.2 Regressions

Since the dietary variables are the main variables of interest, I check the robustness of their relationship with BMI by performing four ordinary least squares (OLS) regressions. The regression results are reported in Appendix Table A.4. The standard errors are reported in parentheses under the coefficient estimates.

Dietary variables are consistently statistically significant in all four regressions. Regression 4 includes the complete set of socio-economic variables and is the regression chosen for the analysis. In Regression 4, the estimated coefficients on the dietary variables PLANTS, DAIRY, FISHSEAFOOD, OTHERANIMAL, EGGS, and POULTRY are statistically significant. CPIFOOD and DJPN are also significant. The adjusted R^2 for this regression is 0.9948. Results are reported in Table 3.6.

Table 3.6

Regression 4 Results

Variable	***Parameter Estimate***	***Standard Error***	***Pr > |t|***
Intercept	18.11478***	1.57483	<.0001
Plants	0.00117***	0.00025577	<.0001
Dairy	0.00201***	0.00055391	0.0004
FishSeafood	-0.00572***	0.00146	0.0002
OtherAnimal	-0.00621***	0.00155	0.0001
Eggs	0.02322***	0.00498	<.0001
Poultry	0.01507***	0.00169	<.0001
Pork	0.00021436	0.00080896	0.7916
MuttonGoat	-0.00803	0.00742	0.2821
Beef	-0.00010145	0.00285	0.9716
Internet	0.00260	0.00277	0.3503
CPIFood	0.01243***	0.00205	<.0001
Qsmoke	-0.00002029	0.00003225	0.5307
Urban	0.00992	0.01483	0.5049
HrsWork	0.00006608	0.00006987	0.3465
RGDPK	0.00000237	0.00001335	0.8591
DFIN	1.05566***	0.33711	0.0023
DFRA	-0.32483	0.27467	0.2397
DGRE	0.67993	0.64025	0.2908
DJPN	-2.18380***	0.45019	<.0001
Year1980	0.42845	0.31814	0.1811

(continued)

Variable	*Parameter Estimate*	*Standard Error*	*Pr > |t|*
Year1981	0.36409	0.31140	0.2451
Year1982	0.26507	0.30769	0.3910
Year1983	0.36965	0.29329	0.2104
Year1984	0.32857	0.28486	0.2514
Year1985	0.28312	0.27806	0.3110
Year1986	0.21252	0.27238	0.4371
Year1987	0.15117	0.27641	0.5857
Year1988	0.03646	0.27375	0.8943
Year1989	0.02698	0.26638	0.9195
Year1990	0.02525	0.25706	0.9219
Year1991	-0.02981	0.24886	0.9049
Year1992	-0.03515	0.24840	0.8877
Year1993	0.05797	0.24004	0.8097
Year1994	0.03209	0.23016	0.8894
Year1995	0.02699	0.22371	0.9042
Year1996	0.03813	0.21589	0.8602
Year1997	0.05165	0.20418	0.8008
Year1998	-0.01799	0.19063	0.9250
Year1999	-0.07347	0.18396	0.6905
Year2000	-0.06068	0.16462	0.7132
Year2001	-0.12459	0.14841	0.4032
Year2002	-0.15143	0.12913	0.2437
Year2003	-0.14386	0.11608	0.2181
Year2004	-0.10988	0.10724	0.3080
Year2005	-0.08745	0.10079	0.3877
Year2006	0.02215	0.09406	0.8143
Year2007	-0.02374	0.08887	0.7899
Year2008	-0.08713	0.08118	0.2857

Note. n = 150
$^*p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$

A significant, positive parameter estimate was expected for each of the dietary variables. Consumption is thought to increase BMI regardless of the sources of kcal being consumed. However, the variables FISHSEAFOOD, OTHERANIMAL, MUTTONGOAT and BEEF all have negative signs, though the latter two were not statistically significant. This may be due to country-specific consumption patterns. For example, the Japanese have a lower BMI and consume the most fish and seafood compared to the other countries.

3.2.3 Dietary Effect on BMI

In this section, I develop a simple method to measure how a shift in dietary composition or a shift in both composition and total kcal from the 2009 U.S. diet to the four alternative diets would affect U.S. BMI. These are the two scenarios considered in Chapter 2. I use 2009 because it is the ending year of the sample.

The starting point is to take the total differential of the regression such that the change in BMI is expressed as the sum of the weighted changes (measured in kcal) of the nine dietary variables to model a change in each of the diets. The weight for each dietary variable change is the regression coefficient associated with it. Denoting each dietary variable by x_i, for i =1, 2, …, 9, the change in BMI (*dBMI*) can be written as:

$$\sum_{i=1}^{9}\left[\frac{\partial BMI}{\partial x_i} \times dx_i\right] = dBMI \qquad (2)$$

The change in the dietary variable, dx_i, is measured by the difference in current (2009) consumption of each dietary component i between the reference country and the United States; that is, $dx_i = \left(x_i^j - x_i^{USA}\right)$, where $j = \{Finland, France, Greece, Japan\}$.

Referring to Appendix Table A.5 and focusing on Japan, the column labeled dx_i gives the difference between the 2009 U.S. and Japanese kcal intake in each of the nine dietary categories. Take beef and poultry, for example. A shift to Japanese diet would require reducing consumption beef by 82 kcal and reducing consumption of poultry by 137 kcal. On the other hand, if one considers fish and seafood, a shift to Japanese diet would require increasing fish and seafood consumption by 115 kcal. Appendix Table A.5 shows the calculations for Scenario 2 which is a more straight-forward calculation so it is presented first. Table 3.7 sums up the changes by diet. The summation reveals that a switch from the U.S. to a Japanese-type diet results in a decrease in U.S. BMI by 3.05 units. A switch to a Mediterranean, French, or Nordic diet using countries Greece, France, and Finland as respective representatives results in decrease in U.S. BMI by 2.60, 2.19, and 2.78 units, respectively.

Table 3.7

Change in U.S. BMI for Scenario 2: Shift in Both Dietary Composition and Total Kcal

	Japanese	**Mediterranean**	**French**	**Nordic**
dBMI	-3.05	-2.60	-2.19	-2.78

The results in Table 3.7 assume that the total kcal in the U.S. diet level declines to the respective total kcal of each of the diets the U.S. diet is being compared with. In what follows, Scenario 1 is considered in which I measure the change in U.S. BMI holding the total kcal consumed at the U.S. level of 3,688 for each of the diets. As shown in the first numerical column of Appendix Table A.6, this is accomplished by dividing each diet category within each diet by the total calories of that diet and multiplying the result by 3,688 kcal. Take plants in the Japanese diet, for example. They represent 79 percent of the kcal in that diet. As shown in the second numerical column, if the U.S. diet were to be 79 percent plant-based, it would require consumption of 2,923 calories from plants. The rest of the columns were calculated in the same way as the columns in Appendix Table A.5.

The resulting total change in U.S. BMI given a shift in diet composition but holding total kcal fixed at the U.S. level in 2009 is shown in Table 3.8. Obviously, the change in BMI is of smaller magnitude than in Scenario 2 when U.S. kcal consumption is allowed to adjust downwards.

Table 3.8

Change in U.S. BMI for Scenario 1: Shift in Dietary Composition, Total Kcal Constant at U.S. Level

	Japanese	**Mediterranean**	**French**	**Nordic**
dBMI	-1.48	-2.57	-1.96	-2.13

3.2.4 Summary of Results

The largest reduction in U.S. BMI (-3.05) occurs when shifting to a Japanese-type diet and reducing consumption to the Japanese level of 2,723 total kcal per capita per day. Similarly, shifting consumption composition and total kcal to a Nordic or Mediterranean-type diet would lead to more than a two-unit reduction in U.S. BMI. When only shifting the diet composition but continuing to consume 3,688 kcal per capita per day, the results indicate that U.S. BMI could decline by 2.57 units at most when one shifts to a Mediterranean-type diet.

The effects of shift to a Mediterranean-type diet on U.S. BMI are -2.57 and -2.60 for a shift and a shift plus a change in total kcal, respectively. This highlights the similarity in the total amount of kcal consumed in the Mediterranean diet and the U.S. diet which are 3,661 and 3,688, respectively. The effect on U.S. BMI is more dramatic from a shift to a Japanese-type diet. There is a 1.48 unit decrease in U.S. BMI when shifting to the Japanese dietary composition, holding total kcal constant to the U.S. level; and 3-unit decrease if U.S. kcal consumption declines to the Japanese level. It is worth highlighting again that only a shift in composition toward a Mediterranean-type diet would result in a decrease in BMI by approximately 2.6 units. This is a substantial decrease in BMI due to only shifts in types of food products consumed. Comparatively, the greatest decrease in BMI is just over 3 units when shifting composition and total kcal. This result requires a decrease of almost 1,000 kcal per day. Therefore, it is plausible that dietary composition can affect BMI even without decreasing caloric intake.

3.2.5 Caveats

There are several data limitations. First, BMI is an imperfect measure of weight status. Secondly, as mentioned in the related literature, energy expenditure data are hard to find, especially at the country level. The urban variable may indicate the level of physical activity, as used in other studies, but it is an imperfect proxy. Lack of a clear physical activity variable may bias the regression results. The estimated coefficients for the dietary variables may reflect differences in the level of physical activity among the countries rather than purely representing BMI differences due to the product categories. In the model, I try to account for this with a dummy variable for each country, anticipating that the dummy variable would pick up in-country variations of lifestyle, including physical activity.

The estimated coefficients, taken at face-value, seem to indicate that a calorie is not just a calorie, but that the source of the calorie matters. By definition, a calorie is a measurement of heat energy and by the first law of thermodynamics, energy cannot be created or destroyed. Yet, there may be different ways our bodies use the calories. This is an on-going research topic, especially surrounding weight-loss diets (Bray et al., 2012; Buchholz & Schoeller, 2004).

Another limitation with the data is that the Food Balance Sheets report the food supply, rather than the food consumed. It is likely that the numbers used are an overestimate of the food consumed, and if there are systematic differences in food waste among the countries, relying on food supply data could introduce an additional source of bias into the estimates.

3.3 Conclusions

The results indicate that by shifting to any of the other representative healthier diets, U.S. BMI decreases whether the total kcal consumed is held constant or allowed to adjust to the respective amounts in each of the four other diets. As in Chapter 2, larger effects are observed when reducing kcal since U.S. consumers have the highest daily per capita kcal intake in the sample.

Without a clear energy expenditure variable, it is difficult to interpret the coefficients in the model. Additional specifications of the model should be explored as data become available. With those caveats in mind, in the next chapter I use the estimated changes in U.S. BMI from switching to the other diets to measure the resulting changes in U.S. health costs.

CHAPTER 4: DIETARY COSTS

The objective of this chapter is to use the results from Chapters 2 and 3 to estimate the costs associated with diet-related environmental and health damages. By environmental damages and health damages, I mean the CO_2 emissions and BMI associated with the alternative diets discussed in the previous chapters.

4.1 Cost of CO_2 Emissions Associated with Dietary Choice

The social cost of carbon (SCC) is a commonly used estimate that monetizes damages due to carbon emissions (Greenstone & Looney, 2011). The Interagency Working Group on the Social Cost of Carbon translates emissions into atmospheric GHG concentrations and then to temperature change in order to project economic damages today and into the future. The central value estimated in 2010 was $21 per ton of CO_2 emissions. Using the SCC and emissions calculations from Chapter 2, the cost of CO_2 for all diets is calculated.

Table 4.1 shows the costs associated with Scenario 1, where dietary composition shifts, holding total kcal at the U.S. daily level of 3,688 per capita. From Chapter 2, the U.S. diet generates 0.410 tons of CO_2 emitted per capita per year. At $21 per ton, the emissions are valued $8.62. Extrapolating this dollar amount over the entire population in the United States in 2009 amounts to $2.7 billion dollars annually.

Table 4.1

Environmental Costs for Scenario 1: Shift in Dietary Composition, Total Kcal Constant at U.S. Level

Diet	**Tons of CO_2[a]***	**Cost[b]***	**Cost Difference Relative to U.S. Diet***	**Cost Difference Relative to U.S. Diet (millions)**	**Percentage Difference**
Japanese	0.394	$8.27	-$0.35	-$107.7	-4.1%
Mediterranean	0.388	$8.14	-$0.48	-$146.2	-5.5%
U.S.	0.410	$8.62			
French	0.484	$10.16	$1.54	$474.3	17.9%
Nordic	0.518	$10.88	$2.26	$695.5	26.2%

[a] Reported in Chapter 2, Table 2.4
[b] *Tons of CO_2* column multiplied by $21
* Per capita per year

As shown in Table 4.1, when evaluating the costs of only shifting dietary composition, the Mediterranean diet is the lowest-cost diet at $8.14 per capita annually. This is a decrease of 48 cents from the U.S. diet. If the entire U.S. population adopted a Mediterranean-type diet, there would be a $146 million dollars in environmental cost savings in the form lower carbon emissions.

The costs due to a shift in dietary composition and decrease in total kcal, or Scenario 2, are shown in Table 4.2. The cost for the United States is the same while the emissions, and thus cost, decrease for each of the representative diets. The lowest-cost diet in terms of CO_2 emissions is the Japanese diet at $6.10 per capita per year. If the U.S. population consumed a Japanese-type diet in composition and caloric intake, the resulting reductions in environmental damage would be $773.2 million dollars annually. Conversely, the French diet is the highest-cost diet, at $9.73 per capita annually. By consuming a French-type diet, the CO_2 cost would increase from the U.S. level by $341.2 million dollars across the entire population, an increase of almost 13 percent.

Table 4.2

Environmental Costs for Scenario 2: Shift in Both Dietary Composition and Total Kcal

Diet	**Tons of CO_2[a]***	**Cost[b]***	**Cost Difference Relative to U.S. Diet***	**Cost Difference Relative to U.S. Diet (millions)**	**Percentage Difference**
Japanese	0.291	$6.10	-$2.51	-$773.2	-29.2%
Mediterranean	0.385	$8.08	-$0.53	-$164.5	-6.2%
U.S.	0.410	$8.62			
French	0.463	$9.73	$1.11	$341.2	12.9%
Nordic	0.455	$9.56	$0.94	$288.9	10.9%

[a] Reported in Chapter 2, Table 2.6
[b] *Tons of CO_2* column multiplied by $21
* Per capita per year

4.2 Health Cost Associated with Dietary Choice

4.2.1 Cost of Obesity

Extensive work has been done on the cost of obesity which can inform this research since diets are an important factor in weight status. In 2009, the national health expenditure in the United States was $2.5 trillion, 17.9 percent of GDP (Martin, Lassman, Washington, Catlin, & Team, 2012). In OECD countries, between 1 to 3 percent of health expenditures can be attributed to obesity. In the United States, this percentage is between 5 to 10 percent (OECD, 2012).

There are higher costs associated with an obese individual compared to a normal weight individual for both direct and indirect costs. Direct costs include medical visits and pharmaceuticals whereas indirect costs include presenteeism and absenteeism, both indicators of productivity (Finkelstein, Stromotne, & Popkin, 2010). Additionally, disability and worker's compensation claims are submitted more frequently and with higher pay-outs for obese employees. There have been many estimates attempting to measure and understand these costs, both at an aggregate and individual level.

In 1998, the total economic costs of obesity were estimated to be $99.2 billion, $51.64 billion of which are attributed to direct costs, measured in 1995 dollars (Wolf & Colditz, 1998). For the same year, Finkelstein, Fiebelkorn, and Wang (2003) estimate obesity-related expenditures to be $78.5 billion. Finkelstein, Trogdon, Cohen, and Dietz (2009) estimate obesity-related medical expenses in 2008 were as much as $147 billion, 10 percent of total medical spending. Their data allow them to separate the estimates by payer (Medicare, Medicaid, and Private) and, further, by the type of service. Finkelstein et al. (2012) forecast obesity rates into 2030 and estimate that if the 2010 obesity level is maintained, $549.5 billion could be saved.

On an individual level, OECD reports that health expenditures are 25 percent higher for an obese individual compared to a normal-weight individual (OECD, 2012).

4.2.2 Linking Diet to Health Costs

To link health costs (hcosts) to diet, I use the following relationship:

$$\frac{dhcosts}{ddiet} = \frac{dhcosts}{dBMI} \times \frac{dBMI}{ddiet} \tag{3}$$

The relationship states that the change in health costs due a change in diet is the product of the change in health costs due to a change in BMI and the change in BMI due to a change in diet. The latter was the subject of Chapter 3. The former I obtain from a study by Wang et al. (2006).

In the study, Wang et al. (2006) estimate the marginal health cost for a unit increase in U.S. BMI. Their sample consisted of 372,979 active and retired employees and spouses who chose an indemnity or preferred provider option (PPO) medical insurance plan from the General Motors Corporation and International Union, United Automobile, Aerospace and Agricultural Implement Workers of America. The average pay-out in the sample of normal weight individuals is $2,750 for medical claims and $1,179 for drug claims, summing to a total of $3,929 in annual healthcare costs. The marginal cost for each increased unit of BMI over 25 is $119.70 for medical costs and $82.60 for pharmaceutical costs. Thus, the increase in health costs associated with one unit increase in BMI is $202.30, or $\frac{dhcosts}{dBMI}$ in Equation 3.

While BMI and health costs have a nonlinear, J-shaped relationship, the section of the cost curve associated with a BMI between 25 and 45 kg/m^2 is linear and increasing. Since 28.45 was the average BMI in the United States in 2009 and BMI would remain above 25 irrespective of a shift to any of the other diets considered in this thesis, the estimates from Wang et al. (2006) are used. Results are shown in Table 4.3 for a shift in diet, holding kcal constant at 3,688, the U.S. level in 2009.

Table 4.3

Health Costs for Scenario 1: Shift in Dietary Composition, Total Kcal Constant at U.S. Level

Diet	**Change in BMI[a]***	**Cost Difference Relative to U.S. Diet[b]***	**Cost Difference Relative to U.S. Diet (billions of dollars)**	**Percentage Difference**
Japanese	-1.48	-$299.73	-$92.2	-3.7%
Mediterranean	-2.57	-$519.37	-$159.8	-6.4%
French	-1.96	-$396.05	-$121.9	-4.9%
Nordic	-2.13	-$430.69	-$132.5	-5.3%

[a] Reported in Chapter 3, Table 3.8
[b] *Change in BMI* column multiplied by $202.30
* Per capita per year

Results show that cost savings are realized for dietary shifts to the other four diets evaluated relative to the average diet in the United States. Savings of up to $519 per capita per year in health costs are possible when choosing the Mediterranean-type diet.

Health costs could be reduced in the United States by almost $160 billion dollars, reducing the current total health costs of $2.5 trillion by over 6.4 percent.

Cost savings are more pronounced when one shifts dietary composition, but also reduces calories to the respective level consumed in the other diets as explored in Scenario 2. The annual health cost savings of shifting both dietary composition and total kcal intake ranges from $444 to $617 per capita in the United States which is shown in Table 4.4. The Japanese diet is the lowest-cost diet. Health costs in the United States could be reduced by $190 billion dollars if the entire population adopted a Japanese-type diet.

Table 4.4

Health Costs for Scenario 2: Shift in Both Dietary Composition and Total Kcal

Diet	**Change in BMI[a]***	**Cost Difference Relative to U.S. Diet[b]***	**Cost Difference Relative to U.S. Diet (billions of dollars)**	**Percentage Difference**
Japanese	-3.05	-$617.36	-$190.0	-7.6%
Mediterranean	-2.60	-$526.65	-$162.0	-6.5%
French	-2.19	-$443.63	-$136.5	-5.5%
Nordic	-2.78	-$562.24	-$173.0	-6.9%

[a] Reported in Chapter 3, Table 3.7
[b] *Change in BMI* column multiplied by $202.30
* Per capita per year

4.3 Aggregated Costs

Since the SCC and the health costs attributed to BMI are both reported in annual U.S. dollars, a money metric, they are aggregated for a total cost of diets. This methodology of aggregating costs to estimate the full cost of food is used by Pretty, Ball, Lang, and Morison (2005) who consider different stages of the lifecycle. It is also utilized to assess the total external costs of agriculture in the United Kingdom (Pretty, et al., 2000) and to assess the costs of pesticide use in U.S. agriculture (Pimentel, et al., 1992).

Table 4.5 shows the cost savings results when accounting for both environmental and health damages, relative to the U.S. diet given a shift in dietary composition, but holding daily caloric intake constant.

Table 4.5

Aggregate Costs for Scenario 1: Shift in Dietary Composition, Total Kcal Constant at U.S. Level

Diet	**Total Cost Difference Relative to U.S. Diet[a]***	**Total Cost Difference Relative to U.S. Diet (billions of dollars)**
Japanese	-$300.08	-$92.3
Mediterranean	-$519.84	-$160.0
French	-$394.51	-$121.4
Nordic	-$428.43	-$131.8

[a] Calculated by summing the *Cost Difference Relative to U.S. diet* columns from Tables 4.1 and 4.3
* Per capita per year

All of the alternative diets represent a cost savings compared to the average diet consumed in the United States. Even though the French and Nordic diets have higher carbon costs relative to the U.S. diet, there is a net savings when the health costs were added. Evaluating just a shift in dietary composition, the Mediterranean-type diet generates the largest cost-savings.

Table 4.6 presents the total cost savings of Scenario 2 when shifting dietary composition and reducing total caloric intake to the levels in the respective diets. Again, all of the alternative diets result in cost savings, even greater than the savings associated with a dietary shift. In this case, the Japanese-type diet generates the largest cost-savings.

Table 4.6

Aggregate Costs for Scenario 2: Shift in Both Dietary Composition and Total Kcal

Diet	**Total Cost Difference Per Capita Relative to U.S. Diet[a]***	**Total Cost Difference Relative to U.S. Diet (billions of dollars)**
Japanese	-$619.87	-$190.7
Mediterranean	-$527.18	-$162.2
French	-$442.52	-$136.2
Nordic	-$561.30	-$172.7

a: Calculated by summing the *Cost Difference Relative to U.S. diet* columns from Tables 4.2 and Table 4.4
* Per capita per year

4.4 Sustainability Criteria

The lowest-cost diet is the most sustainable given the definition of sustainable diets presented in the introduction. Therefore, in Scenario 1, when considering just a shift in dietary composition, holding total kcal constant at the U.S. level, the Mediterranean diet is the most sustainable. When considering a shift plus a reduction in total kcal as in Scenario 2, the Japanese diet is the most sustainable.

The cost estimates indicate that if one focuses on only the environmental impact or the health impact of diets, the analysis is incomplete. Because the effects of diets are widespread, aggregation of costs is important, especially when considering sustainability criteria.

4.5 Addressing Costs

Although the cost of diets has been calculated, this research leaves many questions yet to be answered on how to address these costs and will likely require creative public policy.

An assumption made in this analysis is that people shift their diets. Although that may seem rather restrictive, in practice, food consumption preferences and habits may explain more of the variation in diets than prices, meaning that people are unlikely to change their consumption patterns in the short-term. Some evidence of that was recently provided by Dubois, Griffith, and Nevo (2013). Their results show that although prices and nutritional characteristics of the food account for some variation among countries, they do not tell the whole story. Rather, the economic environment and differences in preferences have explanatory power as well.

There is considerable economic research on externalities of consumption and pollution is often used as an example of an externality. The CO_2 emissions associated with the different diets outlined in Chapter 2 are clearly an externality. If the goal is to maximize social welfare, the externalities must be internalized. Rather than applying a Pigouvian-like tax on goods relative to their environmental impact, environmental labeling has been initiated on certain products and by the European supermarket Tesco, although discontinued (Vaughan, 2012). However, as noted by Tukker et al. (2011), "directly intervening into consumer choices about diets of the EU populations for environmental reasons alone was seen as an unrealistic policy proposition. Given problems like obesitas and the fast rising health costs in the EU, discussing the need for diet change from a health perspective was seen as much more viable" (p. 1777). Small changes in consumer behavior are observed in response to carbon-labeling (Vanclay et al., 2011).

With health-related consequences of diet, it is unclear whether there is an externality present. The high costs associated with obesity are not, by themselves, justification for government intervention from an economic standpoint since they do not indicate market failure (Finkelstein & Strombotne, 2010). The current discussion is around who the obesity costs are financed by. The question remains whether the obese internalize at least some of these costs through lower pay. Finkelstein, Strombotne, and Popkin (2010) find that the cost is not passed on to the obese employee. Conversely, OECD (2012) reports obese individuals earn up to 18 percent less than normal-weight individuals. Burnello, Michaud, and Sanz-de-Galdeano (2009) report that the wages of the obese are lower, keeping productivity rates constant; therefore the additional health cost is internalized.

In their work, Brunello et al. (2009) estimate the additional health expenditures for obese Americans over 55 years of age to be $19,898 over their lifetime using hypothetical individuals. This expense is covered by out-of-pocket payments, private insurance, and public sources at 14 percent, 42 percent and 44 percent of the total, respectively. Bhattacharya and Sood (2005) frame obesity in the context of an externality where some of the costs are public while others are private. They estimate the societal cost to be $150 per capita. Finkelstein et al. (2009) find that $1,429 or 41.5 percent more is spent by all payers on obese individuals.

There have been comparisons to smoking since both smoking and obesity rates are pressing public health concerns and based on behavior. “However, eating is not like smoking. Eating is both an absolute necessity and intrinsically healthy, whereas tobacco has unquestionably been shown to pose serious health risks” (Senauer & Gemma, 2006). This indicates that an excise tax on certain food groups may not be appropriate (recent examples include a soda tax or a meat tax) for a few reasons. First, this tax would affect the entire population and decrease welfare for those who are not over-consuming. Secondly, as indicated by Drewnowski and Spector (2004), these taxes may affect the poor disproportionately. Thirdly, most taxes focus on one or a few specific food products. Diets are a composition of multiple food products, so one must think of the entire food bundle and substitution effects must be taken into account. Fourthly, government intervention through taxes is seen as paternalistic and coercive if no externality exists. A subsidy on healthy foods or incentives to increase energy expenditure may be better policy options. "For example, the federal tax code could be amended to give tax breaks or tax credits for health club memberships and for participation in fat-reduction programs, particularly those like Weight Watchers that stress limiting portion size and overall food intake (current tax law only allows such tax breaks in limited cases that do not cover the majority of Americans)" (Carfaro, Primack, & Zimdahl, 2006, p. 553). Either way, data collection on obesity and energy expenditure will be essential for a complete analysis.

4.6 Caveats

There are a few caveats with the cost estimates worth bringing forth. These cost estimates should not be considered the full cost of diets. As noted in Chapter 2, the environmental costs considered are those related to the production, only one stage of a product's life cycle. Additionally, only CO_2 emissions are considered. If N_2O and CH_4 emissions were included, the analysis would be more complete since they are two other primary GHGs emitted during production. Other environmental damages could be considered such as soil quality, water, loss of biodiversity, etc. Therefore, the environmental costs are grossly underestimated.

The health costs are also estimates given the interconnectedness of obesity and other diseases. Wang et al. (2006) try to adjust for this statistically and report that the true value of a one unit increase in BMI is in the range of \$63.2 to \$202.3; between \$38.1 to \$119.7 for medical costs and \$25.1 to \$82.6 for drug costs.

4.6 Conclusions

The aggregated costs of diets calculated in this chapter may provide a basis for policy analysis and considerations for consuming more sustainably. For a shift in dietary composition, the Mediterranean diet is the lowest-cost. When both a shift and reduction in caloric consumption are considered, the Japanese diet is the lowest-cost and most sustainable diet. It is worth highlighting again that there are cost savings by choosing any of the other diets in both scenarios. Even though the French and Nordic diets have a higher CO_2 costs relative to the U.S. diet, there is a net cost savings when the health costs are factored in.

CHAPTER 5: SUMMARY AND CONCLUSIONS

This thesis contributes to the literature on sustainable consumption by using scenario analysis to evaluate the environmental and health costs of the U.S. diet relative to the French, Japanese, Mediterranean, and Nordic diets, identified in the literature as healthier diets.

As a first step in estimating environmental costs, the energy efficiencies of each diet are calculated in Chapter 2 by decomposing each of the diets into their respective components. Then, the total dietary efficiencies are translated into CO_2 emissions. There were two scenarios considered; in Scenario 1, dietary composition shifts while total kcal is held constant at the U.S. level and in Scenario 2, both dietary composition and total kcal are allowed to shift to the respective level in each diet. The main finding in Chapter 2 is that CO_2 emissions and the percentage of animal products in one's diet are not linearly related. That is, one must consider the mix of animal products, not only the amount when determining environmental damages. In Scenario 1, the Mediterranean diet results in the least amount of emissions while in Scenario 2, the Japanese diet results in the least.

As a first step to measuring health costs, Chapter 3 estimates the association between the five diets and BMI using pooled cross-section time-series data on five countries: France, Finland (representing the Nordic diet), Greece (representing the Mediterranean diet), Japan, and the United States. The dependent variable in the model, BMI, is regressed on dietary variables, socioeconomic variables, and other dummy variables. The dietary variables are the same categories used in Chapter 2 when calculating individual energy efficiencies. The Mediterranean diet results in the largest reduction (-2.57) in BMI in Scenario 1. The Japanese diet results in the largest reduction (-3.05) in Scenario 2. The take-away from the results Chapter 3 is that a shift in dietary composition may have substantial effects on BMI. In fact, in each alternative diet and both scenarios considered, BMI is reduced from the U.S. level.

Chapter 4 measures the environmental and health costs associated with the diet-related environmental and health damages estimated in Chapters 2 and 3, respectively. The environmental cost of each diet is measured by the total tons of CO_2 emissions calculated in Chapter 2 for each diet multiplied by the social cost of carbon per ton. Findings suggest that the U.S. diet is more environmentally costly than the Japanese and Mediterranean diets and less environmentally costly compared to the French and Nordic diets.

Regarding diet-related health damages, the health costs are calculated by multiplying a published estimate of the effect BMI on health costs by the change U.S. BMI when shifting to one of the alternative dietary scenarios, estimated in Chapter 3. All four alternative diets in both scenarios result in reduced BMI and, hence, reduced health costs.

When environmental costs from CO_2 emissions are added to health costs, the Mediterranean diet is the least costly under Scenario 1, while the Japanese diet is the least costly in Scenario 2.

Several caveats about the limitations of the thesis are in order. First, the environmental damages are limited to CO_2 emissions. A more complete accounting of the environmental damages would account for the energy inputs throughout a product's life-cycle. Second, what contributes to obesity rates is still an open question. Moreover, BMI is an imperfect measure of weight status and health costs. Third, the FAO food supply data represent average diets, which likely overestimates actual caloric intake. Fourth, this research does not address demand or supply response considerations. For a large-scale shift to a more sustainable diet to take place, the supply of foods that make up the diet would have to change to accommodate the shift either through domestic production, imports, or both. Granted that some of the shift may be induced by a change in non-price factors, relative prices may play a larger role in inducing consumers to demand foods that make up more sustainable diets and induce producers to supply them. Additionally, the role of U.S. farm policy in shaping incentives to consume and produce such foods. These could be areas of future research. Despite the caveats, this thesis provides a useful basis upon which future research can assess the costs of transitioning to sustainable diets more fully.

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APPENDIX

Table A.1

Energy Efficiencies

Product	kcal protein[a] / kcal input	kcal total[b] / kcal protein	kcal total[c] / kcal protein	kcal output[d] / kcal input
Livestock & Livestock Products				
Lamb	0.02	3.99	2.3	0.07
Beef cattle[e]	0.03	3.46	2.3	0.09
Eggs	0.03	2.67	3.1	0.07
Pork	0.07	3.65	2.5	0.26
Dairy (milk)	0.07	4.54	3.9	0.32
Turkey	0.10	1.55	n/a	0.15
Chicken	0.25	2.71	2.9	0.68
Mean Poultry				0.42
Mean Livestock				0.23
Fish[f]				
Herring	0.50	2.06		1.03
Perch, ocean	0.25	1.21		0.30
Salmon, pink	0.13	1.45		0.18
Cod	0.05	1.06		0.05
Tuna	0.05	1.10		0.05
Haddock	0.04	1.06		0.05
Halibut	0.04	1.15		0.05
Salmon, king	0.03	2.10		0.05
Shrimp	0.01	1.22		0.01
Lobster	0.01	1.09		0.01
Mean Fish & Seafood				0.18
Grains & Legumes				
Corn				3.84
Wheat				2.13
Oats (MN)				5.10
Rice				2.24
Sorghum				1.96
Soybean				3.19
Dry Bean				1.81

Product	$\frac{\text{kcal protein}^{a}}{\text{kcal input}}$	$\frac{\text{kcal total}^{b}}{\text{kcal protein}}$	$\frac{\text{kcal total}^{c}}{\text{kcal protein}}$	$\frac{\text{kcal output}^{d}}{\text{kcal input}}$
Fruit & Vegetables				
Apples (Eastern US)				0.61
Oranges (FL)				1.02
Potatoes				1.33
Spinach				0.23
Tomatoes				0.26
Brussels Sprouts				0.69

[a] Data are from Pimentel and Pimentel (2008).
[b] Data are from U.S. Department of Agriculture, Agricultural Research Service (2013). Raw meat values were chosen from the database, ground meat chosen for beef, pork and lamb for consistency.
[c] Data are from Eshel and Martin (2006) for comparison purposes. Per conversation with Eshel, "data for liquid 3 percent fat milk" was used to calculate (kcal total/kcal protein) for milk, but I was not able to locate the exact data used for the other livestock products. It is expected that these columns would not change overtime.
[d] The values were calculated by multiplying first and second numeric columns for livestock. These energy efficiencies are used to calculate e_i for each diet. The higher the value, the more efficient the product is.
[e] Beef cattle that are started on forage and grain finished.
[f] Fish or seafood are all raw, wild-caught since global capture production is greater than aquaculture production (FAO, Fisheries and Aquaculture Department, 2012). Atlantic herring, Pacific cod, slipjack tuna, Atlantic and Pacific halibut and northern lobster were chosen as representative of their broader categories based on market share of U.S. commercial fishing industry (National Marine Fisheries Service, 2011). Interestingly, nutritional data differs based on species and location caught.

Table A.2

Energy Efficiency of Animal-Based Portion of Each Diet

Diet	**Animal Product**	**Caloric Fraction of Animal-Based Portion**[a]	**Energy Efficiencies**[b]	**Weighted mean of animal-based portion (e_i)**[c]
Japanese	Beef	0.05	0.09	0.23
	Mutton & Goat	0.00	0.07	
	Pork	0.16	0.26	
	Poultry	0.10	0.42	
	Eggs	0.13	0.07	
	Animal, Other	0.03	0.23	
	Fish & Seafood	0.27	0.18	
	Dairy	0.25	0.32	
Mediterranean	Beef	0.06	0.09	0.26
	Mutton & Goat	0.08	0.07	
	Pork	0.14	0.26	
	Poultry	0.06	0.42	
	Eggs	0.04	0.07	
	Animal, Other	0.03	0.23	
	Fish & Seafood	0.04	0.18	
	Dairy	0.55	0.32	
U.S.	Beef	0.11	0.09	0.28
	Mutton & Goat	0.00	0.07	
	Pork	0.13	0.26	
	Poultry	0.19	0.42	
	Eggs	0.05	0.07	
	Animal, Other	0.07	0.23	
	Fish & Seafood	0.04	0.18	
	Dairy	0.41	0.32	
French	Beef	0.07	0.09	0.27
	Mutton & Goat	0.02	0.07	
	Pork	0.19	0.26	
	Poultry	0.08	0.42	
	Eggs	0.05	0.07	
	Animal, Other	0.08	0.23	
	Fish & Seafood	0.07	0.18	
	Dairy	0.45	0.32	

Diet	Animal Product	Caloric Fraction of Animal-Based Portion[a]	Energy Efficiencies[b]	Weighted mean of animal-based portion (e_i)[c]
Nordic	Beef	0.07	0.09	0.27
	Mutton & Goat	0.00	0.07	
	Pork	0.30	0.26	
	Poultry	0.05	0.42	
	Eggs	0.03	0.07	
	Animal, Other	0.02	0.23	
	Fish & Seafood	0.06	0.18	
	Dairy	0.46	0.32	

[a] Data are from FAO (2013b).
[b] Data are from the forth numeric column in Appendix A.1 where a higher value represents higher efficiency.
[c] The values were calculated as a weighted mean of all animal-based products or e_i used in Equation 1. A higher value reflects a more efficient diet.

Table A.3

Summary Statistics

Variable	Label	N	Mean	Std Dev	Minimum	Maximum
BMI	BMI	150	24.9223333	1.6432957	21.7000000	28.4500000
Plants	Plants	150	2344.34	323.9679500	1704.00	2878.00
Dairy	Dairy	150	428.2866667	173.9002004	117.0000000	770.0000000
FishSeafood	FishSeafood	150	77.6600000	63.3776187	27.0000000	226.0000000
OtherAnimal	OtherAnimal	150	57.8533333	39.8422033	19.0000000	146.0000000
Eggs	Eggs	150	53.0400000	14.0013806	32.0000000	80.0000000
Poultry	Poultry	150	77.1333333	50.7907494	11.0000000	210.0000000
Pork	Pork	150	189.7066667	111.7134726	58.0000000	374.0000000
MuttonGoat	MuttonGoat	150	21.9000000	27.9793188	1.0000000	82.0000000
Beef	Beef	150	80.2800000	34.6882801	16.0000000	141.0000000
Internet	Internet	150	19.5661982	26.8724825	0	83.6700000
CPIFood	CPIFood	150	74.4246667	22.9031545	6.1000000	103.5000000
Qsmoke	Qsmoke	150	2208.48	939.5298382	0	3741.00
Urban	Urban	150	74.5048200	8.3440997	57.7340000	89.6284000
HrsWork	HrsWork	150	1801.89	317.7608191	0	2208.00
RGDPK	RGDPK	150	28507.72	7839.34	14268.68	45431.03

Table A.4

Selected Regression Results

Variable	Model 1	Model 2	Model 3	Model 4
Intercept	21.26909***	21.98154***	22.38338***	18.11478***
	(0.7830)	(1.1747)	(1.1425)	(1.5748)
Plants	0.00107***	0.000672***	0.00094633***	0.00117***
	(0.0003)	(0.0003)	(0.0002)	(0.0003)
Dairy	0.00402***	0.00322***	0.00203***	0.00201***
	(0.0005)	(0.0005)	(0.0005)	(0.0006)
FishSeafood	-0.00713***	-0.00592***	-0.00634***	-0.00572***
	(0.0018)	(0.0018)	(0.0015)	(0.0015)
OtherAnimal	-0.01283***	-0.00951***	-0.00406***	-0.00621***
	(0.0013)	(0.0013)	(0.0013)	(0.0016)
Eggs	-0.01655***	-0.02029***	0.02072***	0.02322***
	(0.0042)	(0.0042)	(0.0048)	(0.0050)
Poultry	0.01835***	0.01445***	0.01338***	0.01507***
	(0.0017)	(0.0017)	(0.0016)	(0.0017)
Pork	0.00161**	-0.000198	-0.000676	0.000214
	(0.0007)	(0.0008)	(0.0008)	(0.0008)
MuttonGoat	-0.00969**	-0.002270	-0.01121*	-0.008030
	(0.0040)	-(0.0023)	(0.0058)	(0.0074)
Beef	0.000965	0.00972***	-0.002750	-0.000101
	(0.0027)	(0.0028)	(0.0028)	(0.0029)
Internet		0.00347**	0.00645***	0.002600
		(0.0017)	(0.0013)	(0.0028)
CPIFood		0.00465***	0.00981***	0.01243***
		(0.0018)	(0.0015)	(0.0021)
Qsmoke		-0.000089**	-0.000044	-0.000020
		(0.0000)	(0.0000)	(0.0000)
Urban		-0.006710	-0.02049*	0.009920
		(0.0117)	(0.0110)	(0.0148)
HrsWork		0.000113	0.000084	0.000066
		(0.0001)	(0.0001)	(0.0001)
RGDPK		0.000012	-0.000011	0.000002
			(0.0000)	(0.0000)
DFIN			0.86847***	1.05566***
			(0.2918)	(0.3371)
DFRA			-0.54949**	-0.324830
			(0.2698)	(0.2747)

(continued)

Variable	Model 1	Model 2	Model 3	Model 4
DGRE			-0.130550	0.679930
			(0.4930)	(0.6403)
DJPN			-2.38809***	-2.1838***
			(0.4366)	(0.4502)
Year1980				0.428450
				(0.3181)
Year1981				0.364090
				(0.3114)
Year1982				0.265070
				(0.3077)
Year1983				0.369650
				(0.2933)
Year1984				0.328570
				(0.2849)
Year1985				0.283120
				(0.2781)
Year1986				0.212520
				(0.2724)
Year1987				0.151170
				(0.2764)
Year1988				0.036460
				(0.2738)
Year1989				0.026980
				(0.2664)
Year1990				0.025250
				(0.2571)
Year1991				-0.029810
				(0.2489)
Year1992				-0.035150
				(0.2484)
Year1993				0.057970
				(0.2400)
Year1994				0.032090
				(0.2302)
Year1995				0.026990
				(0.2237)
Year1996				0.038130
				(0.2159)

(continued)

Variable	Model 1	Model 2	Model 3	Model 4
Year1997				0.051650
				(0.2042)
Year1998				-0.017990
				(0.1906)
Year1999				-0.073470
				(0.1840)
Year2000				-0.060680
				(0.1646)
Year2001				-0.124590
				(0.1484)
Year2002				-0.151430
				(0.1291)
Year2003				-0.143860
				(0.1161)
Year2004				-0.109880
				(0.1072)
Year2005				-0.087450
				(0.1008)
Year2006				0.022150
				(0.0941)
Year2007				-0.023740
				(0.0889)
Year2008				-0.087130
				(0.0812)
N	150	150	150	150
F-value	881.94	748.74	1303.18	597.8
R-squared	0.9827	0.9882	0.9948	0.9965
Adj. R-squared	0.9816	0.9869	0.9940	0.9948

$*p < 0.05$. $**p < 0.01$. $***p < 0.001$

Table A.5

Change in BMI for Scenario 2: Shift in Both Dietary Composition and Total Kcal

Diet	**Product Category**	**Difference From U.S.**	**Regression Coefficients**	**Change in BMI**	**Total Change in BMI**
		dx_i	$\frac{\partial BMI}{\partial x_i}$	$\left[\frac{\partial BMI}{\partial x_i} \times dx_i\right]$	$dBMI$
Japanese	Animal, Other	-48	-0.00621	0.30	-3.05
	Beef	-82	-0.00010	0.01	
	Dairy	-273	0.00201	-0.55	
	Eggs	22	0.02322	0.51	
	Fish & Seafood	115	-0.00572	-0.66	
	Mutton & Goat	-2	-0.00803	0.02	
	Plants	-517	0.00117	-0.60	
	Pork	-42	0.00021	-0.01	
	Poultry	-137	0.01507	-2.06	
Mediterranean	Animal, Other	-42	-0.00621	0.26	-2.60
	Beef	-58	-0.00010	0.01	
	Dairy	49	0.00201	0.10	
	Eggs	-17	0.02322	0.51	
	Fish & Seafood	-2	-0.00572	0.01	
	Mutton & Goat	67	-0.00803	-0.54	
	Plants	133	0.00117	0.16	
	Pork	-12	0.00021	0.00	
	Poultry	-146	0.01507	-2.20	

(continued)

Diet	**Product Category**	**Difference From U.S.**	**Regression Coefficients**	**Change in BMI**	**Total Change in BMI**
		dx_i	$\frac{\partial BMI}{\partial x_i}$	$\left[\frac{\partial BMI}{\partial x_i} \times dx_i\right]$	$dBMI$
	Animal, Other	33	-0.00621	-0.20	
	Beef	-28	-0.00010	0.00	
	Dairy	114	0.00201	0.23	
	Eggs	1	0.02322	0.02	
French	Fish & Seafood	40	-0.00572	-0.23	-2.19
	Mutton & Goat	18	-0.00803	-0.14	
	Plants	-327	0.00117	-0.38	
	Pork	92	0.00021	0.02	
	Poultry	-100	0.01507	-1.51	
	Animal, Other	-37	-0.00621	0.23	
	Beef	-23	-0.00010	0.00	
	Dairy	150	0.00201	0.30	
	Eggs	-21	0.02322	-0.49	
Nordic	Fish & Seafood	33	-0.00572	-0.19	-2.78
	Mutton & Goat	0	-0.00803	0.00	
	Plants	-661	0.00117	-0.77	
	Pork	237	0.00021	0.05	
	Poultry	-127	0.01507	-1.91	

Table A.6

Change in BMI for Scenario 1: Shift in Dietary Composition, Total Kcal Constant

Diet	**Product Category**	**Caloric Fraction of Diet**	**kcal**	**Difference from U.S.**	**Regression Coefficients**	**Change in BMI**	**Total Change in BMI**
				dx_i	$\frac{\partial BMI}{\partial x_i}$	$\left[\frac{\partial BMI}{\partial x_i} \times dx_i\right]$	$dBMI$
Japanese	Animal, Other	0.01	26	-41	-0.00621	0.26	-1.48
	Beef	0.01	38	-72	-0.00010	0.01	
	Dairy	0.05	194	-222	0.00201	-0.45	
	Eggs	0.03	103	49	0.02322	1.14	
	Fish & Seafood	0.06	209	170	-0.00572	-0.97	
	Mutton & Goat	0.00	1	-2	-0.00803	0.01	
	Plants	0.79	2923	248	0.00117	0.29	
	Pork	0.03	122	-10	0.00021	0.00	
	Poultry	0.02	76	-117	0.01507	-1.77	
Mediterranean	Animal, Other	0.01	25	-42	-0.00621	0.26	-2.57
	Beef	0.01	52	-58	-0.00010	0.01	
	Dairy	0.13	468	52	0.00201	0.11	
	Eggs	0.01	37	-17	0.02322	-0.39	
	Fish & Seafood	0.01	37	-2	-0.00572	0.01	
	Mutton & Goat	0.02	71	68	-0.00803	-0.54	
	Plants	0.77	2829	154	0.00117	0.18	
	Pork	0.03	121	-11	0.00021	0.00	
	Poultry	0.01	47	-146	0.01507	-2.19	

(continued)

Diet	Product Category	Caloric Fraction of Diet	kcal	Difference from U.S.	Regression Coefficients	Change in BMI	Total Change in BMI
				dx_i	$\frac{\partial BMI}{\partial x_i}$	$\left[\frac{\partial BMI}{\partial x_i} \times dx_i\right]$	$dBMI$
French	Animal, Other	0.03	104	37	-0.00621	-0.23	-1.96
	Beef	0.02	86	-24	-0.00010	0.00	
	Dairy	0.15	554	138	0.00201	0.28	
	Eggs	0.02	57	3	0.02322	0.08	
	Fish & Seafood	0.02	83	44	-0.00572	-0.25	
	Mutton & Goat	0.01	22	19	-0.00803	-0.15	
	Plants	0.66	2452	-223	0.00117	-0.26	
	Pork	0.06	234	102	0.00021	0.02	
	Poultry	0.03	97	-96	0.01507	-1.44	
Nordic	Animal, Other	0.01	34	-33	-0.00621	0.20	-2.13
	Beef	0.03	99	-11	-0.00010	0.00	
	Dairy	0.17	644	228	0.00201	0.46	
	Eggs	0.01	38	-16	0.02322	-0.38	
	Fish & Seafood	0.02	82	43	-0.00572	-0.25	
	Mutton & Goat	0.00	3	0	-0.00803	0.00	
	Plants	0.62	2292	-383	0.00117	-0.45	
	Pork	0.11	420	288	0.00021	0.06	
	Poultry	0.02	75	-118	0.01507	-1.78	