DEMAND ANALYSIS OF DAIRY PRODUCTS IN THE UNITED STATES

A Dissertation

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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May 2021

Major Subject: Agricultural Economics

ABSTRACT

Dairy products play an important role in the American diet. We analyzed the long-run and short-run demands for a granular array of dairy and dairy alternative products in the United States based on three essays, where three different data sets from Nielsen Homescan panel were used.

In the first essay, we estimated the demand of eleven dairy and dairy alternative products based on a cross-sectional data for calendar year 2015. Two-step Heckman procedure was utilized to deal with the data-censoring problem. Socio-demographic characteristics were found to have significant impacts on the demands. This study supported confidence in the use of coupons in dairy promotion. The own-price elasticities of plant–based milk alternatives and Greek yogurt were found to be elastic. This research provided a detailed analysis on the long-run demand of a granular array of dairy products, which could be used as a baseline of the market study for dairy stakeholders.

In the second essay, we used two demand system models, quadratic almost ideal demand system and the Barten's synthetic model, to capture the interrelationships among the demands of different dairy categories based on the monthly time-series data from 2010 to 2015. The uncompensated and compensated own-price elasticities for plant-based milk alternatives and Greek yogurt were found to be elastic. This study conducted an analysis for short-run price and expenditure elasticities for a dairy complex at the aggregated over households level, which could provide insights in terms of pricing strategy for the relative dairy companies.

In the third essay, we used the panel data for calendar years 2010 to 2015 to examine the marginal effects of households socio-demographic characteristics on the demand of thirteen dairy and dairy alternative products based on two-way random effects models. Results show that households with higher income level, no children under 18, younger household heads, college educated household heads purchased more quantities of Greek yogurt and plant-based milk alternatives. The own-price elasticities of plant–based milk alternatives and Greek yogurt were found to be inelastic. These findings provided insight in terms of market segmentation strategies and targeting consumers for dairy stakeholders.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Capps, my committee co-chair, Dr. Dharmasena and my committee members, Dr. Wu, Dr. Salin, and Dr. Ishdorj, for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience.

Finally, thanks to my mother and father for their encouragement and love.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee consisting of Professors Oral Capps, Senarath Dharmasena, Ximing Wu, and Ariun Ishdorj of the Department of Agricultural Economics and Professor Victoria Salin of the Department of Agribusiness.

Researcher's own analyses calculated (or derived) based in part on data from The Nielsen Company (US), LLC and marketing databases provided through the Nielsen Datasets at Kilts Center for Marketing Data Center at the University of Chicago Booth School of Business. The conclusions drawn from the Nielsen data are those of the researcher and do not reflect the views of Nielsen. Nielsen is not responsible for, had no role in, and was not involved in analyzing and preparing the results reported herein.

All other work conducted for the thesis (or) dissertation was completed by the student independently.

Funding Sources

Graduate study was supported by a teaching assistantship from Texas A&M University and a research assistantship from The Agribusiness, Food, and Consumer Economics Research Center (AFCERC).

NOMENCLATURE

AIDS	Almost Ideal Demand System
BP	Breusch and Pagan
GLS	Generalized Least Squares
LSDV	Least Squares Dummy Variable Regression
OLS	Ordinary Least Squares
PMA	Plant-based Milk Alternatives
QUAIDS	Quadratic Almost Ideal Demand System
USDA	United States Department of Agriculture

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CHAPTER I

INTRODUCTION

Dairy products play an important role in the American diet. Dairy foods contain vital nutrients for health and maintenance of the human body. The notable nutrients include calcium, vitamin D, protein, and potassium. Especially, dairy products are the primary source of calcium in the American diet, considered to be important for bone health (ChooseMyPlate.gov, Dec 14, 2018). ChooseMyPlate of the United States Department of Agriculture (USDA) suggests that diets containing 3 cups of dairy products per day can improve bone mass. With consumers concerned more and more about their health conditions, especially obesity, low-fat and fat-free dairy foods also are of interest.

The major dairy products consumed in the United States include fluid milk, cheese, butter, yogurt, and ice cream. Based on the per capita consumption data of different dairy products from USDA, Statista, and Economic Research Service. In the U.S. dairy market, the consumption of total dairy products has been increasing for recent decades. However, per capita consumption of fluid milk has declined. At the same time, the per capita consumption of cheese and butter has shown an increasing trend, especially for cheese, which has been one of the most important forces shaping the U.S. dairy industry.

The changes in the demand for dairy products have been a major concern to policy makers, dairy producers, and other stakeholders in the dairy industry. Information such as elasticities and socio-demographic effects are useful for stakeholders in dairy market to make decisions both in business and policy arenas. For example, retailers are interested in knowing the effectiveness of applying coupon in dairy promotion, and potential pricing strategies on dairy products to increase the dairy product intake, hence contributing to increase intake of vital nutrients available. Thus, demand analyses for these major dairy products are warranted.

Most previous dairy demand analyses focused on one or two major dairy products, especially milk and cheese. However, a wider array of dairy products and more dairy alternative products have been offered to US consumers in the most recent decade. This situation has caused notable changes of the dairy market structure as well as an evolution of consumer habits on dairy products. One representative example is Greek yogurt. According to the Nielsen Homescan retail data, the market penetration of Greek yogurt increased by 167% from 20% in 2010 to 53.7% in 2015. At the same time, more dairy alternative products, such as almond milk, coconut milk, and soy milk, have been consumed by Americans. The market penetration of the dairy alternative products has increased from 16.6% in 2010 to 28.8% in 2015. Thus, it is important to consider the interrelationship between different dairy products when conducting dairy demand analysis. While some researchers have conducted demand analyses associated with the dairy complex, the most comparable to the present study was done in 2010. Because the dairy market structure has changed, stakeholders need to base their market strategies on more current information.

In this light, a more granular array of dairy products will be used to estimate the demand for these products. Three different types of data sets will be used. A time-series data set is used to estimate the elasticities at the aggregated household level, which represents a short-term reaction of the dairy market. A demand system approach will be used to capture interrelationships among different dairy products. A panel data set is used to find out the effects of household socio-demographic factors on the demand for the dairy products. The most recent cross-sectional data set, at least available to researchers in the Agribusiness, Food, and Consumer Economics Research Center in the Department of Agricultural Economics at Texas A&M University, will be used to study the situation in the dairy market. This cross-sectional view is considered to be a long-run depiction of the dairy market.

CHAPTER II

CROSS-SECTIONAL ANALYSIS OF THE DEMAND FOR DAIRY PRODUCTS

Introduction

Background

Dairy products play an important role in the American diet. Dairy foods contain vital nutrients for the health and maintenance of the human body. The notable nutrients include calcium, vitamin D, protein, and potassium. Especially, dairy products are the primary source of calcium in the American diet, considered to be important for bone health (ChooseMyPlate.gov, Dec 14, 2018). ChooseMyPlate of the United States Department of Agriculture (USDA) suggests that diets containing 3 cups of dairy products per day can improve bone mass. With consumers concerned more and more about their health conditions, especially obesity, low-fat and fat-free dairy foods also are of interest.

The major dairy products consumed in the United States include fluid milk, cheese, butter, yogurt, and ice cream. Figures 1 to 6 show the quarterly per capita consumption of different dairy products. The data for fluid milk, cheese, and butter are from the USDA, while the data for yogurt and ice cream are obtained from USDA, Statista, and Economic Research Service. In the U.S. dairy market, the consumption of total dairy products has been increasing for recent decades. However, per capita consumption of fluid milk has declined. At the same time per capita consumption of cheese and butter has shown an increasing trend, especially for cheese, which has been one of the most important forces shaping the U.S. dairy industry.

Changes in the demand for dairy products have been a major concern to policymakers, dairy producers, and other stakeholders in the dairy industry. Information such as elasticities and socio-demographic effects are useful for stakeholders associated with the dairy sector in order to make decisions in business and policy arenas. For example, retailers are interested in knowing the effectiveness of the use of coupons in dairy promotions; as well retailers wish to develop pricing strategies concerning dairy products to increase revenue. As such, demand analyses for dairy products are warranted.

In general previous dairy demand analyses have focused on one or two dairy products, especially milk and cheese. However, a wider array of dairy products and more dairy alternative products have been offered to U.S. consumers in the past ten years. This situation has led to notable changes in the dairy industry (Dharmasena and Capps, 2014). For example, consider Greek yogurt and dairy alternative products (e.g. almond milk, coconut milk, and soy milk). According to data from the Nielsen Homescan panel, the market penetration of Greek yogurt increased sharply from 20% in 2010 to 54% in 2015. The market penetration of dairy alternative products has increased from 17% in 2010 to 29% in 2015. It is important to re-consider demands interrelationships among different dairy as well as dairy alternative products. The most recent study was done in 2010 (Davis, Dong, Blayney, and Owens, 2010).

Objectives

The general objective of this study is to estimate the demands for a granular array of dairy products based on cross-sectional data for the calendar year 2015, the most recent data set available for analysis in the Agribusiness, Food, and Consumer Economics Research Center in the Department of Agricultural Economics at Texas A&M University. The specific objectives are as follows:

(1) To examine household demand for thirteen different dairy products in the United States and household response to price and income changes. In this study, own-price elasticities, cross-price elasticities, and income elasticities for the dairy complex are

estimated. Because of zero purchases by households for some products, the Heckman two-step procedure is used to deal with the censoring problem.

(2) To estimate the impacts of socio-demographic factors on the demand for the granular array of dairy products. This information is useful to develop marketing strategies.

(3) To examine the effectiveness of the use of coupons in the dairy promotion. In this study, the value of the coupon is estimated to capture household responses on coupon promotion. This examination helps retailers to develop more effective promotion strategies.

Though this research does not reflect the most recent dairy market information subject to data availability, most of the major dairy products available to American consumers for recent years are included. In this light, this research provides dairy stakeholders with more updated and more comprehensive information about the dairy market as baseline.

Literature Review

Many studies concerning the demand for dairy products have been conducted in the extant literature. Most of the previous studies focus on one or two individual dairy products, notably milk and cheese. Bouhlal, Capps, and Ishdorj (2013) estimated the demands for 14 different cheese varieties using a censored random effect panel Tobit model based on Nielsen Homescan panel data for calendar years 2005 and 2006. The 14 cheese varieties included Mozzarella, Colby, Cheddar, Swiss, the remaining natural cheese, processed slices, loaves, snack cheese, cream cheese, Ricotta, grated cheese, specialty/imported cheese, shredded cheese, and cottage cheese. The demands for natural cheese varieties generally were found to be elastic, while most processed cheese varieties were found to be inelastic. At the same time, most of the varieties were revealed to be normal goods except for processed slices. The results showed that demographic factors, such as household size, education status, and race affected household demand for natural and processed cheeses.

Yogurt has been named one of the most popular foods in the last ten years (Dharmasena, Okrent, and Capps, 2014). Robinson (2017) estimated own-price, cross-price, and expenditure elasticities of demand for five brands: Dannon, Yoplait, Stonyfield, Chobani, and Private Label. A seemingly unrelated regression (SUR) model was used in this analysis based on weekly Nielsen Homescan data from 2009 to 2011. The own-price elasticities from the SUR model for Chobani (-2.64) and Dannon (-1.43) were in the elastic range while for the other brands, the own-price elasticities were in the inelastic range. According to the income elasticities from the SUR model, Yoplait (1.98), Stonyfield (1.64), Dannon (2.34), and Chobani (2.89) were all found to be luxury goods, while Private Label or store brand yogurt (0.38) was found to be necessities.

Keller (2018) developed twelve different probit models to estimate the effects of socio-economic and demographic factors concerning the propensity of purchasing Greek yogurt and non-Greek yogurt with and without reference to brands using Nielsen Homescan panel data for the calendar year 2015. Prices and income had significant effects on every profile associated with purchasing any type of yogurt. Socio-demographic variables varied depending on the types of yogurt products. The results showed that socio-demographic variables such as region, race, education status, presence of children, and age of household head impacted the demand for Greek yogurt and non-Greek yogurt.

Gould (1996) estimated own-price and cross-price elasticities for whole milk, 2 percent milk, and skim milk based on Nielsen Marketing Research household level panel data from April 1991 to March 1992. A demand system was estimated derived from the indirect translog utility function; demographic variables also were included in the analysis. Findings from this study found that the own-price elasticities of whole milk (-0.803), skim milk (-0.593), and 2% milk (-0.512) to be inelastic. As well, milk beverages with different fat levels were found to be substitutes.

Yen (2002) used a censored translog model to estimate the demand for household fat and oil demand with cross-sectional data from 1987-1988. Compensated and uncompensated own-price elasticities of butter were found to be -1.161 and -1.132 respectively.

Davis *et al.* (2009) applied a censored translog demand system model to analyze the purchases of three ice cream product categories based on Nielsen Homescan retail data for the calendar year 2005. Household socio-demographic factors, such as marital status, age, race, education, female employment status, and location were considered in this analysis. The results revealed that the uncompensated own-price elasticity for bulk ice cream was unitary elastic. Price and consumer income were the main determinants of demand for ice cream products. Several demographic variables were important demand factors such as employment status of the female head of the household, region, race, marital status, children present in the home, and education status of the female head.

Davis *et al.* (2011) identified price and socio-demographic factors that affect the demand for cheese using a censored AIDS model based on Nielsen Homescan retail data for the calendar year 2006. They estimated the own-price elasticities of natural cheese and processed cheese to be -1.84 and -1.63 respectively. Both types of cheese were found to be substitutes. Demographic variables had statistically significant impacts on natural, cottage, processed, and grated cheeses such as household size, age of the female head of the household, region locations, education status of the female head, and race.

Heien and Wessells (1988) estimated an AIDS model with 12 food items based on the Household Food Consumption Survey, a cross-sectional data set over the period 1977 to 1978. Own-price elasticities for milk (-0.63), butter (-0.73), and cheese (-0.52) were found to be in the inelastic range. Socio-economic characteristics of the household estimated in this study included urbanization, region, tenancy of the residents, number and age of people living in the household, race of the respondent, recipients of food stamps, frequency of major food shopping occasions, and classification of household by gender of the head. Most of these demographic variable have statistically significant impacts on the demand for milk, cheese, and butter.

Maynard and Liu (1999) estimated the demand for dairy products including white milk, flavored milk, cheese, butter, yogurt, ice cream, and novelties using a double-log model, a linearized AIDS model, and a nested differential demand model based on weekly Nielsen Homescan retail data for the years 1996 through 1998. Most of the own-price elasticities estimated from all three models were found to be in the elastic range, different from previous studies. At the same time, the household level data were aggregated to national levels, but in doing so, this aggregation failed to capture demographic effects.

The most recent study that analyzed a demand system for the dairy complex was conducted by Davis et al. (2010). The demands for twelve dairy products and margarine using a censored AIDS model and Nielsen Homescan data for calendar year 2007 were estimated. As well, demographic variables were included in the model. Ten of the twelve uncompensated and compensated own-price elasticities were statistically significant. The compensated and uncompensated own-price elasticities were estimated to be -0.77 and -0.91 for bulk ice cream, -1.21 and -1.21 for sherbet/ice milk, -1.08 and -1.19 for refrigerated yogurt, -1.26 and -1.26 for frozen yogurt, -1.72 and -1.73 for drinkable yogurt, -1.65 and -1.70 for whole milk, -1.26 and -1.57 for reduced-fat milk, -1.31 and -1.32 for canned milk, -1.61 and -1.73 for natural cheese, -0.89 and -0.99 for processed cheese, -1.64 and -1.68 for cottage cheese, -1.81 and -1.87 for butter, -0.90 and -0.95 for margarine. Substitution relationships among ice cream, reduced-fat milk, and natural cheese were evident. For socio-demographic variables, household size positively influenced the purchases of ice milk, drinkable yogurts, whole milk, reduced-fat milk, processed cheese, and margarine. As well, purchases of bulk ice cream, frozen yogurt, canned milk, cottage cheese, and butter were positively influenced by the age of the female head of the household.

Analytical Framework

In this study, cross-sectional data from the Nielsen Homescan Panel for the 2015 calendar year are used to conduct demand analysis of the dairy complex. The dairy complex includes seven main categories: (1) fluid milk; (2) butter; (3) margarine; (4) cheese; (5) ice cream; (6) yogurt; and (7) plant-based milk alternatives. Furthermore, the category of fluid milk is divided into three sub-categories: organic white milk, non-organic white milk, and flavored milk (mainly chocolate milk). Three sub-categories are included in the non-organic white milk category: whole milk, low-fat milk (1% and 2%), and skim milk. The category cheese is divided into two sub-categories: processed cheese and natural cheese. The category yogurt also is divided into two sub-categories: Greek yogurt and non-Greek yogurt. Plant-based milk alternatives are included in the dairy complex because products such as soymilk and almond milk have been gaining more attention from consumers. Plant-based milk alternatives are hypothesized to be substitutes to conventional white milk. In this study, products of two brands- Blue Diamond and Silk are used to represent plant-based milk alternatives, since these two brands have the largest market shares in this category. Margarine is also included in the dairy complex because of the expected relationships with butter, although it is not a dairy product. So thirteen products will be analyzed, namely organic white milk, whole milk, low-fat milk, skim milk, flavored milk, butter, margarine, processed cheese, natural cheese, Greek yogurt, non-Greek yogurt, ice cream, plant-based milk alternatives. A schematic depicting all thirteen dairy and dairy alternative products is shown in Figure 7.

Heckman Sample Selection Model

Because of zero purchases for some products (Amemiya, 1974), the Heckman two-step procedure is used to deal with the censoring problem (Wooldridge, 1995; Puhani, 2000). The Heckman sample selection model is as follows.

First Step:

$$d_{ih}^{*} = \boldsymbol{Z}_{\boldsymbol{ih}}'\boldsymbol{\alpha}_{\boldsymbol{i}} + v_{ih} ,$$

$$d_{ih} = \begin{cases} 1 & if\ d_{ih}^{*} > 0 \\ 0 & if\ d_{ih}^{*} < 0 \end{cases}, \qquad (1)$$

Second Step:

$$y_{ih}^{*} = f(\boldsymbol{X}_{\boldsymbol{ih}}, \boldsymbol{\beta}_{\boldsymbol{i}}) + \epsilon_{ih},$$

$$y_{ih} = d_{ih}y_{ih}^{*},$$

$$(i = 1,2 \ldots, m; h = 1,2, \ldots, H) \qquad (2)$$

where

d_{ih}^{*} = unobserved variable representing the difference between the utility of good i and the reserved utility for household h when he/she make a purchase decision.

d_{ih} = observed dichotomous variable representing the purchase decision of household h for good i . $d_{ih} = 1$ means she/he will buy, while $d_{ih} = 0$ means she/he will not.

Z_{ih} = a vector of exogenous variables that affects the purchase decision.

α_i = a vector of parameters in the purchase decision equation

$y_{ih} =$ observed dependent variables representing the consumed quantity of good i.

$f(\boldsymbol{X}_{\boldsymbol{ih}}, \boldsymbol{\beta}_{\boldsymbol{i}})$ = demand function.

X_{ih} =a vector of exogenous variables that affect consumed quantity.

β_i = a vector of parameter in the demand function

v_{ih}, ϵ_{ih} = random errors.

The conditional mean of y_{ih} is

$$E(y_{ih}|X_{ih}, \boldsymbol{Z_{ih}}, d_{ih} = 1) = f(\boldsymbol{X_{ih}}, \boldsymbol{\beta_i}) + E(\boldsymbol{\epsilon_{ih}}|v_{ih} > -\boldsymbol{Z'_{ih}}\boldsymbol{\alpha_i}) \tag{3}$$

Assume v_{ih}, ϵ_{ih} have a bivariate normal distribution as follows:

$$\begin{bmatrix}\epsilon_{ih} \\ v_{ih}\end{bmatrix} \sim BN\left[\begin{bmatrix}0 \\ 0\end{bmatrix}, \begin{bmatrix}\sigma_{1h}^2 & \sigma_{12h} \\ \sigma_{21h} & \sigma_{2h}^2\end{bmatrix}\right].$$

Thus

$$E(\boldsymbol{\epsilon_{ih}}|v_{ih} > -\boldsymbol{Z'_{ih}}\boldsymbol{\alpha_i}) = \frac{\sigma_{12h}}{\sigma_{2h}} \frac{\phi\left(-\frac{\boldsymbol{Z'_{ih}}\alpha_i}{\sigma_{2h}}\right)}{1-\Phi\left(-\frac{\boldsymbol{Z'_{ih}}\alpha_i}{\sigma_{2h}}\right)}. \tag{4}$$

$\phi(.)$ and $\Phi(.)$ denote the density and cumulative distribution function of standard normal distribution.

In order to run the regression for the conditional mean of y_{ih} , the inverse Mills ratio (IMR) should be obtained first, which is defined as follows.

$$IMR = \lambda\left(-\frac{\boldsymbol{Z'_{ih}}\alpha_i}{\sigma_{2h}}\right) = \frac{\phi\left(-\frac{\boldsymbol{Z'_{ih}}\alpha_i}{\sigma_{2h}}\right)}{1-\Phi\left(-\frac{\boldsymbol{Z'_{ih}}\alpha_i}{\sigma_{2h}}\right)} = \frac{\phi\left(\frac{\boldsymbol{Z'_{ih}}\alpha_i}{\sigma_{2h}}\right)}{\Phi\left(\frac{\boldsymbol{Z'_{ih}}\alpha_i}{\sigma_{2h}}\right)}. \tag{5}$$

The IMR can be calculated using the probit model from the first step, which is used to regress binary choices. Using the notation in the Heckman sample selection model, the probit model can be specified as follows.

$\Pr(d_{ih} = 1|\, \boldsymbol{Z_{ih}}) = \Pr(d_{ih}^* > 0) = \Pr(\boldsymbol{Z'_{ih}}\boldsymbol{\alpha_i} + v_{ih} > 0) = \Pr(v_{ih} > -\boldsymbol{Z'_{ih}}\boldsymbol{\alpha_i}) = \Pr(v_{ih} < \boldsymbol{Z'_{ih}}\boldsymbol{\alpha_i}) = \Phi(\boldsymbol{Z'_{ih}}\boldsymbol{\alpha_i})$.

$$\Pr(d_{ih} = 0|\, \boldsymbol{Z_{ih}}) = 1 - \Phi(\boldsymbol{Z'_{ih}}\boldsymbol{\alpha_i}) \tag{6}$$

The optimal estimator $\boldsymbol{\widehat{\alpha}_i}$ is estimated to maximize joint likelihood:

$$\mathcal{L}(\boldsymbol{\alpha_i}; \boldsymbol{d_i}, \boldsymbol{Z_i}) = \prod_{h=1}^{H}(\Phi(\boldsymbol{Z'_{ih}}\boldsymbol{\alpha_i})^{d_{ih}}[1 - \Phi(\boldsymbol{Z'_{ih}}\boldsymbol{\alpha_i})]^{(1-d_{ih})}) \tag{7}$$

After plugging the fitted value $\boldsymbol{\widehat{\alpha}_i}$ for $\boldsymbol{\alpha_i}$ into equation (5), the IMR will be calculated. Thus the conditional mean of y_{ih} in the second step will be

$$y_{ih} = f(\boldsymbol{X_{ih}}, \boldsymbol{\beta_i}) + \delta_i \lambda\left(-\frac{Z'_{ih}\alpha_i}{\sigma_{2h}}\right) + \xi_{ih}, \quad (8)$$

where ξ_{ih} is the error term. The parameters to be estimated in the second step are $\boldsymbol{\beta_i}$ and δ_i.

Heteroscedasticity Correction

The appropriate estimation technique for regressions (8) in the second stage is either ordinary (OLS) or generalized least squares (GLS) due to the potential heteroscedasticity problem in the Heckman procedure. Denote $\boldsymbol{\widehat{S}_{ih}} = \boldsymbol{Z'_{ih}}\boldsymbol{\widehat{\alpha}_i}$ and $\hat{\lambda}_{ih} = I\widehat{M}R_{ih}$. Then, for each observation, the weight for GLS is specified as

$$\left(1 + \widehat{\theta}_\iota(\boldsymbol{\widehat{S}_{ih}}\,\hat{\lambda}_{ih} - \hat{\lambda}_{ih}^2)\right)^{-\frac{1}{2}},$$

where $\boldsymbol{\widehat{S}_{ih}}$ and $\hat{\lambda}_{ih}$ are estimated from probit model in the first step, and $\widehat{\theta}_\iota$ is estimated by regressing each squared residual μ_{ih}^2, which is obtained from the OLS estimation of equation (8), on $\boldsymbol{\widehat{S}_{ih}}\,\hat{\lambda}_{ih} - \hat{\lambda}_{ih}^2$. In order to determine OLS or GLS, the following hypothesis should be tested.

$$H_0\colon \widehat{\theta}_\iota = 0$$

If $H_0\colon \widehat{\theta}_\iota = 0$ cannot be rejected, then OLS is the appropriate method. If $H_0\colon \widehat{\theta}_\iota = 0$ is rejected, then GLS is the correct procedure. However, the weight may not be ensured to be determined because there is a square root involved, which requires $1 + \widehat{\theta}_\iota(\boldsymbol{\widehat{S}_{ih}}\,\hat{\lambda}_{ih} - \hat{\lambda}_{ih}^2)$ to be positive. In this case, the OLS is used instead of GLS.

Marginal Effects

In the second step estimation (8), we obtain the parameters for explanatory variables as $\boldsymbol{\widehat{\beta}_i}$. However, we also need to consider the terms related to the inverse Mills ratio in order to capture the appropriate marginal effects. According Saha, Capps, and Byrne (1997), the marginal effect for the j^{th} regressor evaluated at the sample means is given as:

$$ME_{hj} = \frac{\partial E(Y_{hi}/d_{hi}=1)}{\partial X_{hj}} = \widehat{\beta_{\iota J}} - \hat{\delta}_\iota \widehat{\alpha_{\iota J}}(\boldsymbol{\bar{Z}'_\iota}\boldsymbol{\widehat{\alpha}_\iota}\widehat{\bar{\lambda}}_\iota + \left(\widehat{\bar{\lambda}}_\iota\right)^2) \quad (9)$$

If $\hat{\delta}_i$, the coefficient associated with IMR_{ih}, is not significantly different from zero, then there is no sample selection bias. Thus the marginal effects (9) equals to $\widehat{\beta_{ij}}$, the parameter estimates obtained from the estimation of equation (8).

Data

The data contain purchasing records of the thirteen dairy products of 61,380 households for the calendar year 2015. The survey contains expenditure and quantity information for each product for each household. Additionally, based on the literature reviews previously discussed socio-demographic factors are included, namely household size, household income, presence of children, age, education status, race and ethnicity of the household, and region. (Pollak and Wales, 1981) A dummy variable as to whether or not the household used a coupon, as well as the value of coupons are considered in order to examine the impact of coupons on purchase of dairy products.

Prices are not provided in Nielsen Homescan data. Unit values for each household are generated as proxies of the prices by taking the ratio of expenditure and quantity. At times, there are no purchases of the aforementioned products, so the quantity is zero. This situation results in missing values of prices or unit values. To mitigate this issue, we impute prices for product i based on the following auxiliary specification. (Alviola and Capps, 2010)

$$\log\left(Price_{i,obseved}\right)$$
$$= a_0 + a_1 \log\left(Income\right) + a_2 \log\left(Household\ Size\right) + a_3 Region + u_i \qquad (10)$$

For equation (10), the dependent variable is the observed unit value for product i. The explanatory factors include household income, household size, and region. Income generally reflects quality. As such, households with higher incomes are likely to pay higher prices. Households with more members tend to purchase more bulk-packaged products, which are usually cheaper than the same products with conventional package sizes. Region typically is a key factor affecting prices reflecting availability, transportation costs, and other factors. Thus, we expect the parameters a_1

to be positive, a_2 to be negative, and a_3 to vary over nine regional delineations. The unit values for observed purchase records and the imputed unit values for missing observations based on equation (10) are used as the price variables in this study.

Outliers are detected after the unit values are generated. (Rousseeuw and Hubert, 2011) The records of quantity, expenditure, and coupon values for the observations whose unit values that are out of the range of five standard deviations[1] from the mean are deleted. At the same time, records are also deleted for observations with zero unit values. For these observations, households paid nothing for a certain amount of some products such as buy one and get one free.

Table II-1 and II-2 show the continuous and binary variables used in the study. Table II-3 and II-4 show the summary statistics of variables. Table II-5 compares the summary statistics of the observed unit values and imputed unit values for different dairy products. As well, Table II-5 exhibits the market penetration of different dairy products for the calendar year 2015. Table II-6 gives more details about the market penetration for organic and conventional milk, plant-based milk alternatives and conventional milk, yogurt, and cheese. Appendix A.2 provides the details of the price imputation process.

From the summary statistics associated with quantity purchased, U.S. households purchase a notable amount of conventional white milk, despite facing competition from flavored milk, organic milk, and plant-based milk alternatives. For conventional white milk, the average quantity of low-fat milk purchased by households is 2,061.32 ounces per year, followed by skim milk at 1,633.41 ounces per year. Whole milk is third at 1,217.40 ounces per year, but larger than flavored milk (428.18 oz/year), organic milk (971.94 oz/year), and plant-based milk alternatives (383.47 oz/year). The average quantity of butte purchased is 141.16 ounces per year, which is smaller than

[1] In a normal distribution, about 99% of values that lies within three standard deviations of the mean, which is known as "three-sigma rule of thumb". In this study, the unit values follow non-normal distributions, thus, five standard deviations are used instead of three.

the average quantity of margarine purchased (170.65 oz/year). The average quantity of natural cheese purchased (379.58 oz/year) is almost three times that the average quantity of processed cheese purchased (127.99 oz/year). The average quantity of non-Greek yogurt is 336.14 ounces per year, while for Greek yogurt, the average quantity purchased is 221.06 ounces per year.

Second, the average expenditures for organic milk ($56.71/year) and for low-fat milk ($52.77/year) are the highest in the milk category, while flavored milk ($16.10/year) and plant-based milk alternatives ($19.56/year) are the lowest in the milk category. Average expenditure on butter ($32.21/year) is more than double the average expenditure on margarine ($15.78/year). Average expenditure on natural cheese ($99.37/year) is more than three times the average expenditure on processed cheese ($29.21/year). Average expenditures on non-Greek yogurt ($35.70/year) and Greek yogurt ($39.65/year) are similar. Finally, the average expenditure on ice cream is $26.66/year.

Third, skim milk, whole milk, and low-fat milk have almost the same average price, three cents per ounce on average. Prices of flavored milk, organic milk, and plant-based milk alternatives are considerably higher, on the order five to six cents per ounce. Average butter prices are double average margarine prices, 25 cents per ounce compared to 12 cents per ounce. Natural cheese prices on average (29 cents per ounce) are slightly higher than processed cheese prices on average (25 cents per ounce). Average prices of Greek yogurt are notably higher than average prices of non-Greek yogurt (19 cents per ounce as opposed to 12 cents per ounce on average). The average price of ice cream is in the order of 9 cents per ounce.

Fourth, only 1% of 61,380 households used coupons when purchasing organic milk in 2015, while roughly 12% households used a coupon when purchasing low-fat milk. For flavored milk, skim milk, whole milk, and plant-based milk alternatives coupon uses varied from 3% to 6%. Natural cheese has the highest percentage of coupon users at 34%, followed by non-Greek yogurt (20%), processed cheese (19%), Greek yogurt (12%), ice cream (16%), butter (14%), and margarine (12%).

Fifth, the age of household head, income, and household size are continuous variables. The average age of the household head is 54, the average household income is nearly $60,000, and the average household size is 2.38. In this analysis, the United States is divided into nine regions. The respective regions are (1) New England (the base as reference category); (2) Middle Atlantic; (3) East North Central; (4) West North Central; (5) South Atlantic; (6) East South Central; (7) West South Central; (8) Mountain; and (9) Pacific. For the race, 82% of the household heads are white (the base category), 11% are black, 3% are Asian, and 5% are other races, and 6% of the household heads are Hispanic. Slightly more than 80% of the household heads have at least a high school education, and 22% have children under 18 in the household.

Sixth, from Table II-5, the imputed unit values and the observed unit values are very similar. However, the imputed unit values have a much lower variability. In this research, the unit values for observed purchase records and imputed prices for missing records are used as the price variable. Table II-5 also shows the market penetration of different dairy products and alternative dairy products for 2015. In the milk category, low-fat milk has the highest market penetration at 74%, followed by whole milk at 40%, plant-based milk (29%), skim milk (24%), flavored milk (23%), and organic milk (8%). The market penetration for butter is 71%, compared to 61% for margarine. The market penetration for ice cream is 71%. For the cheese category, the market penetration for natural cheese is 96% compared to 86% for processed cheese. For the yogurt category, the market penetration for non-Greek yogurt is 73% compared to 54% for Greek yogurt.

Last, Table II-6 shows the percentage of households who buy organic and conventional milk, plant-based milk alternatives and conventional milk, Greek yogurt and non-Greek yogurt, and natural cheese and processed cheese. In the milk category, 2% of households buy organic milk only, 84% of households buy conventional milk only, and 6% buy both products, while 3% of households buy plant-based milk alternatives only, 72% of households buy conventional milk only, and 18 % buy both products. In the yogurt category, 28% of households buy non-Greek yogurt only, 9% of households buy Greek yogurt only, and 45% buy both products in 2015. In the cheese category, 2% of households buy natural cheese only, 12% of households buy processed cheese only, and 84 % buy both products.

Model

Probit Model

In this study, the Heckman selection model is used to deal with the censoring problem in demand analysis. In the first step, probit models for the thirteen dairy products are estimated to obtain the inverse Mills ratio. The dependent variable is the indicator variable representing the purchase decision of household *h* for the dairy product *i*, one if the purchase is made, and otherwise zero. Explanatory variables used in the probit model include the logarithm of own-price of the product, the logarithm of prices of alternative dairy products, the logarithm of household size, the logarithm of income, the logarithm of the age of the household head, education status, region, race, ethnicity, presence of children, and coupon use of the dairy product (a dummy variable).

The alternative products selected vary depending on the specific dairy product analyzed. For example, for the plant-based milk alternatives, we expect substitution of the products in the fluid milk category, including conventional milk, flavored milk, and organic milk. However, it is difficult to intuitively identify the interrelation with products in the cheese category, the yogurt category, and so on. Thus, we calculated a weighted average price for the products in other dairy categories in the probit specification. The weighted average price is generated by the ratio between the summation of expenditure and the summation of the quantity of these products. At the same time, prices of the dairy products in the same category are highly correlated. For example, the average price of skim milk, whole milk, and low-fat milk are very similar. As such, this situation might cause a degrading collinearity problem when all of the three products are involved in the probit regression for some dairy products. In order to avoid collinearity, the price of conventional milk is used instead of specifying prices for all of the three products in some probit models. A similar situation may also be faced by products in the cheese and yogurt category. Details about the alternative products included in the respective probit models are delivered in Table II-7. It should be noted that the weighted average prices might have missing values if the household did not purchase any products included in the category. Thus, unit values for the category are imputed based on equation (10). For the explanations of the estimated parameters from the probit model, we calculated the marginal effects of the independent variables on the probability of purchasing relative dairy products (see Appendix A.3).

Single-Equation Demand Model

In the second step, single-equation demand functions for each dairy product are estimated. The dependent variable is the logarithm of quantity. The same explanatory variables from the probit model are used except coupon use. Coupon value is used instead of the coupon use indicator variable, which helps to conduct a quantitative analysis about the effectiveness of coupon promotion strategy. Importantly, the inverse Mills ratio obtained from the first step (probit analysis) is included in the regression to correct for the sample selection bias.

The use of single-equation demand functions for each dairy product differs from previous studies that deal with demand system approaches. The reason to use single-equation models are as follows:

(1) This research is conducted based on cross-sectional data at the household level for the calendar year 2015 from the Nielsen Homescan panel, where 61,380 households have been surveyed. From the summary statistics discussed previously, a large number of zero observations occur for different dairy products which pose notable problems in the estimation of demand system models.

(2) With the demand system approach, restrictions such as the homogeneity condition, the adding–up condition, and the symmetry of the Slutsky matrix are imposed. But these

restrictions often are not supported in the literature. (Heien and Wessells, 1988; Davis *et al.*, 2010, Davis *et al.*, 2011).

(3) The single-equation demand model is more flexible and faces less computational difficulties in estimation.

Consequently, based on these reasons, the use of the single-equation demand model is preferred to the demand system approaches.

Empirical Results

SAS 9.4 is used to run the regressions for the Heckman two-step procedure. The empirical results of the probit models for the thirteen products are shown in Table II- 8. The goodness-of-fit and McFadden's R^2 metrics are exhibited in Table II-9. Among the thirteen probit models, Greek yogurt has the largest McFadden's R^2 at 0.22, and whole milk has the lowest McFadden's R^2 at 0.08. Coefficients that are significant at the 5% level have been bolded. The results of the F-tests for region and race in Table II-9 show that the region variables are jointly significant at the 5% level for all thirteen probit models, and the race variables also are jointly significant at 5% significant level for most probit models except for Greek yogurt. In addition, we calculated the marginal effect of the explanatory variables associated with the probability of purchasing the respective dairy products (see Appendix A.3).

Table II-10 shows the test results for heteroscedasticity for the second step regression of the Heckman procedure. As mentioned in the heteroscedasticity correction section, the following hypothesis should be tested.

$$H_0: \widehat{\theta_\iota} = 0$$

If $H_0: \widehat{\theta_\iota} = 0$ cannot be rejected, then OLS is the appropriate method. If $H_0: \widehat{\theta_\iota} = 0$ is rejected, then General Least Square (GLS) is the correct procedure. From Table 10, for flavored milk, low-fat milk, skim milk, whole milk, margarine, natural cheese, processed cheese, Greek yogurt, and non-Greek yogurt, the p-value of $\widehat{\theta_\iota}$ is less than 5%, which means that $H_0: \widehat{\theta_\iota} = 0$ is rejected. Thus, GLS is used to deal with the heteroscedasticity problem for these models.

Table II-11 shows the empirical results for the demand functions for the thirteen products. Table II-12 shows the F test results for region and race, as well as adjusted R^2 for the demand models. Among the thirteen demand models, whole milk and natural cheese have the largest adjusted R^2, 0.32. Organic milk has the lowest adjusted R^2 at 0.10. The F-test results show that the region variables are jointly significant at the 5% level for most products, except for organic milk, and the race variables are jointly significant at 5% level for all thirteen dairy products. As mentioned before, if the coefficient associated with the inverse Mills ratio is significant in the demand model, then marginal effects of the explanatory variables should be corrected based on equation (9). The appropriate marginal effects associated with the thirteen demand models for the thirteen dairy products calculated at the sample mean are shown in Table II-13.

Model 1 Plant-based Milk Alternatives

The significant variables include age, region, race, ethnicity, inverse Mills ratio, price of plant-based milk alternatives, price of conventional milk, price of weighted alternative for plant-based milk products, and coupon value.

Households located in the Mountain and Pacific regions purchase 11%[2] and 6% more plant-based milk alternatives compared to households located in the New England region. Households located in other regions purchase less plant-based milk alternatives compared to households in the New England region, for example, , households located in the East North Central and the West South Central regions, purchase 19% and 18% less plant-based milk alternatives relative to households located in the New England region respectively.

White households purchase the least plant-based milk alternatives compared to all the other races. Other households consume the most plant-based milk alternatives, which is 16 % more than white households. Black and Asian households purchase more plant-based milk alternatives

[2] The percentage is calculated based on the function $[\exp(\beta_i) - 1] * 100$, where β_i is the parameter for binary variables.

relative to white households, by 11% and 14% respectively. Hispanic households purchase 15% more plant-based milk alternatives than non-Hispanic households.

Households with children under 18 buy 5% less plant-based milk alternatives than households without children under 18. Households with at least high school education level buy 13% more plant-based milk alternatives than households with less than high school education.

The elasticity of demand of plant-based milk alternatives with respect to the age of household head is -0.04. As the age of the household head increases, the quantity of plant-based milk alternatives declines.

The own-price elasticity of plant-based milk alternatives is -1.18. The cross-price elasticities of plant-based milk alternatives with respect to conventional milk, organic milk, and flavored milk are all positive; as such these products are substitutes to plant-based milk alternatives. The cross-price elasticity of plant-based milk alternatives with respect to the weighted alternative category of remaining dairy products also is positive, indicating that the products in other dairy categories are substitutes to plant-based milk alternatives. The income elasticity of plant-based milk alternatives is 0.03, indicating that plant-based milk alternatives is a necessity.

The elasticity of coupon value for plant-based milk alternatives is 0.08[3], which means that a 1% increase in coupon value would increase the purchase of plant-based milk alternatives by 0.08%, holding other factors constant.

Model 2 Flavored Milk

The significant variables include household size, household income, age, region, race, inverse Mills ratio, price of flavored milk, price of plant-based milk alternatives, price of conventional milk, and coupon value.

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[3] The elasticity of coupon value is calculated as β_i*Coupon Value at the sample mean, where β_i is the estimated parameter associated with coupon value.

Households located in the South Atlantic and Pacific region purchase 1% and 11% less flavored milk compared to households located in New England region respectively. Households located in other regions purchase more flavored milk compared to households located in the New England region. Households located in the East North Central and the West North Central region, consume 20% and 21% more than households located in the New England region.

White households purchase the most flavored milk compared to all the other races. Black households purchase the least flavored milk, which is 28 % less than white households. Asian and other households purchase 10% and 12% less flavored milk than white households. Hispanic households purchase 8% less flavored milk than non-Hispanic households.

Households with children under 18 purchase 3% more flavored milk than households without children under 18. Households with at least high school education level buy 3% less flavored milk than households with less than high school education.

The elasticity of demand of flavored milk with respect to the age of household head is 0.16. Older household heads purchase more flavored milk than younger household heads.

The own-price elasticity of flavored milk is -1.30. The cross-price elasticities of flavored milk with respect to conventional milk, organic milk, and plant-based milk alternatives are all positive, which means that these products are substitutes to flavored milk. The cross-price elasticity of flavored milk with respect to the weighted alternative category is negative, which means the products in other dairy categories are complements to flavored milk. The income elasticity of flavored milk is 0.03, indicating that flavored milk is a necessity.

The elasticity of coupon value for flavored milk is 0.02, which means that a 1% increase in coupon value would increase the purchase of flavored milk by 0.02%, holding other factors constant.

Model 3 Organic Milk

The significant variables include household size, household income, race, presence of children, inverse Mills ratio, price of organic milk, price of flavored milk, price of weighted alternative for organic milk, and coupon value.

Households located in the New England region purchase the least organic milk compared to households located in other regions. Households in the East South Central and Middle Atlantic region, buy 15% and 13% more organic milk than households located in the New England region.

Asian households purchase the most organic milk compared to all the other races, 30 % more than white households. Black households buy the least organic milk, 27% less than white households. Other households buy 1% more organic milk than white households. Hispanic households purchase 4% more organic milk than non-Hispanic households.

Households with children under 18 buy 43% more organic milk than households without children under 18. Households with at least high school education level consume 17% more organic milk than households with less than high school education.

The elasticity of demand of organic milk with respect to the age of household head is -0.11, thus older household heads purchase less organic milk than younger household heads.

The own-price elasticity of organic milk is -1.00, unitary elastic. The cross-price elasticities of organic milk with respect to conventional milk, flavored milk, and plant-based milk alternatives are all positive, which means that these products are substitutes to organic milk. The cross-price elasticity of organic milk with respect to the weighted alternative category is positive, which means the products in other dairy categories are substitutes to organic milk. The income elasticity of organic milk is 0.19, indicating that organic milk is a necessity.

The elasticity of coupon value for organic milk is 0.01, which means that a 1% increase in coupon value would increase the purchase of organic milk by 0.01%, holding other factors constant.

Model 4 Low-fat Milk

The significant variables include household size, household income, age, region, race, presence of children, inverse Mills ratio, price of low-fat milk, price of whole milk, price of skim milk, price of organic milk, price of flavored milk, price of plant-based milk alternatives, and coupon value.

Households located in the New England region purchase the most low-fat milk compared to households located in other regions. Households located in the South Atlantic regions purchase 25% less than households located in the New England region.

White households buy the most low-fat milk compared to all the other races. Black households purchase the least low-fat milk, 56% less than white households. Asian and other households purchase less low-fat milk than white households, by 53% and 24% respectively. Hispanic households buy 2% more low-fat milk than non-Hispanic households.

Households with children under 18 purchase 9% more low-fat milk than households without children under 18. Households with at least high school education level consume 11% less low-fat milk relative to less-educated households.

The elasticity of demand of low-fat milk with respect to the age of the household head is 0.42, as such older household heads purchase more low-fat milk than younger household heads.

The own-price elasticity of low-fat milk is -1.45. The cross-price elasticities of low-fat milk with respect to whole milk, skim milk, plant-based milk alternatives, and organic milk are positive, which means that these products are substitutes to low-fat milk. The cross-price elasticity of low-fat milk with respect to flavored milk is negative, which means that flavored milk is a complement to low-fat milk. The cross-price elasticity of low-fat milk with respect to the weighted alternative category is negative, which means products in other dairy categories are complements to low-fat milk. The income elasticity of low-fat milk is 0.003, hence household income does not play much of role in affecting the demand for low-fat milk.

The elasticity of coupon value for low-fat milk is 0.02, which means that a 1% increase of the coupon value would lead to a 0.02% increase in the purchases of low-fat milk, holding other factors constant.

Model 5 Skim Milk

The significant variables include household size, household income, age, region, race, inverse Mills ratio, price of skim milk, price of low-fat milk, price of whole milk, price of organic milk, price of flavored milk, price of plant-based milk alternatives, and coupon value.

Households located in the Mountain and Pacific region purchase less skim milk compared to households located in the New England region, by 21% and 27% respectively. Households located in other regions buy more skim milk compared to households located in the New England region. In particular, households in the West North Central region, purchase 144% more skim milk than households located in the New England region.

White households buy the most skim milk compared to all the other races. Black households consume the least skim milk, 71 % less than white households. Asian and other households purchase less skim milk than white households, by 43% and 32% respectively. Hispanic households buy 4% less skim milk than non-Hispanic households.

Households with children under 18 purchase 4% less skim milk than households without children under 18. Households with at least high school education level consume 30% more skim milk than households without a high school education.

The elasticity of demand of skim milk with respect to the age of the household head is 0.47, which means that older household heads purchase more skim milk than younger household heads.

The own-price elasticity of skim milk is -1.63. The cross-price elasticities of skim milk with respect to low-fat milk, whole milk, and plant-based milk alternatives are all positive, which means that these products are substitutes to skim milk. The cross-price elasticities of skim milk with respect to flavored milk and organic milk are negative, which means that these products are complements to skim milk. The cross-price elasticity of skim milk with respect to the weighted alternative category is negative, which means the products in other dairy categories are complements to skim milk. The income elasticity of skim milk is 0.28, which means skim milk is a necessity.

The elasticity of coupon value for skim milk is 0.03, which means that a 1% increase of the coupon value would increase the purchase of skim milk by 0.03%, holding other factors constant.

Model 6 Whole Milk

The significant variables include household size, household income, education, region, race, presence of children, inverse Mills ratio, price of whole milk, price of skim milk, price of low-fat milk, price of flavored milk, price of weighted alternative for whole milk, and coupon value.

Households located in the South Atlantic, East South Central and West South Central region purchase more whole milk compared to households located in the New England region, by 4%, 19%, and 16% respectively. Households located in other regions buy less whole milk compared to households in the New England region. In particular, households located in the East North Central region purchase 22% less than households located in the New England region.

Households that are not white, black or Asian purchase the most whole milk, 6% more than white households. Black purchase 5% more whole milk than white households. No difference in the purchase of whole milk are evident between white and Asian households. Hispanic households buy 4% more whole milk than non-Hispanic households.

Households with children under 18 purchase 3% more whole milk than households without children under 18. Households with at least high school education level purchase 27% less whole milk than households without a high school education.

The elasticity of demand of whole milk with respect to the age of household head is -0.18, which means that older household heads purchase less whole milk than younger household heads.

The own-price elasticity of whole milk is -1.97. The cross-price elasticities of whole milk with respect to low-fat milk, skim milk, organic milk, flavored milk and plant-based milk alternatives are all positive, which means that these products are substitutes to whole milk. The cross-price elasticity of whole milk with respect to the weighted alternative category is negative, which means the products in other dairy categories are complements to whole milk. The income elasticity of whole milk is -0.28, which means whole milk is an inferior good.

The elasticity of coupon value for whole milk is 0.01, which means that a 1% increase in coupon value would lead to a 0.01% increase in the purchase of whole milk, holding other factors constant.

Model 7 Ice Cream

The significant variables include household size, household income, age, region, race, ethnicity, presence of children, inverse Mills ratio, price of ice cream, price of Greek yogurt, and coupon value.

Households located in the Middle Atlantic region purchase 12% less ice cream compared to households located in the New England region. Households located in other regions buy more ice cream compared to households located in the New England region. Households in the West South Central and East South Central regions purchase 32% and 30% more ice cream than households located in the New England region respectively.

White households buy the most ice cream compared to all the other races. Asian households purchase the least ice cream, 28 % less than white households. Black and other households purchase less ice cream than white households, by 21% and 8% respectively. Hispanic households buy 10% less ice cream than non-Hispanic households.

Households with children under 18 purchase 6% less ice cream than households without children under 18. Households with at least high school education level purchase 5% less ice cream than households without a high school education.

The elasticity of demand of ice cream with respect to the age of the household head is 0.51, which means that older household heads purchase more ice cream than younger household heads.

The own-price elasticity of ice cream is -0.83, in the inelastic range. The cross-price elasticity of ice cream with respect to non-Greek yogurt is negative, which means that non-Greek yogurt is complement to ice cream. The cross-price elasticity of ice cream with respect to Greek yogurt is positive, which means that Greek yogurt is substitute to ice cream. The cross-price elasticity of ice cream with respect to the weighted alternative category is negative, which means the products in other dairy categories are complements to ice cream. The income elasticity of ice cream is -0.09, which means ice cream is an inferior good[4].

The elasticity of coupon value for ice cream is 0.06, which means that a 1% increase of the coupon value would increase the purchase of ice cream by 0.06%, holding other factors constant.

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[4] Most literatures revealed positive income elasticity of ice cream, while a negative sign associated with ice cream income elasticity is found to be negative in this study. Note that ice cream is considered to contain relative higher level of sugar than other dairy products. From the aspect of health concern, our results seem more reasonable.

Model 8 Natural Cheese

The significant variables include household size, household income, age, education, region, race, ethnicity, presence of children, inverse Mills ratio, price of natural cheese, price of processed cheese, price of conventional milk, price of weighted alternative for natural cheese, and coupon value.

Households located in the East South Central and West South Central regions purchase 4% and 2% less natural cheese compared to households located in the New England region respectively. Households located in other regions purchase more natural cheese compared to households located in the New England region. Households located in the Mountain and Pacific region, buy more natural cheese than households located in the New England region by 26% and 14% respectively.

White households buy the most natural cheese compared to all the other races. Asian households purchase the least natural cheese, 61% less than white households. Black and other households purchase less natural cheese than white households, by 46% and 15% respectively. Hispanic households purchase 7% less natural cheese than non-Hispanic households.

Households with children under 18 buy 10% less natural cheese than households without children under 18. Households with more education purchase 12% more natural cheese relative to households with less education.

The elasticity of demand of natural cheese with respect to the age of household head is -0.23, which means that older household heads purchase less natural cheese than younger household head.

The own-price elasticity of natural cheese is -1.28. The cross-price elasticity of natural cheese with respect to conventional milk is negative, which means that conventional milk is complement to natural cheese. The cross-price elasticity of natural cheese with respect to processed cheese is positive, which means that processed cheese is a substitute to natural cheese. The cross-price elasticity of natural cheese with respect to the weighted alternative category is positive, which means the products in other dairy categories are primary substitutes to natural cheese. The income elasticity of natural cheese is 0.11, which means that natural cheese is a necessity.

The elasticity of coupon value for natural cheese is 0.05, which means that a 1% increase in coupon value would increase the purchase of natural cheese by 0.05%, holding other factors constant.

Model 9 Processed Cheese

The significant variables include household size, household income, age, education, region, race, ethnicity, presence of children, inverse Mills ratio, price of natural cheese, price of processed cheese, price of conventional milk, and coupon value.

Households located in the Mountain and Pacific regions purchase less processed cheese compared to households located in the New England region, by 2% and 13% respectively. Households located in other regions buy more processed cheese compared to households located in the New England region. Households in the West North Central and East South Central regions purchase more natural cheese than households located in the New England region, by 40% and 46% respectively.

White households buy the most processed cheese compared to all the other races. Asian households purchase the least processed cheese, 42% less than white households. Black and other households purchase less processed cheese than white households, by 31% and 11% respectively. Hispanic households buy 13% less processed cheese than non-Hispanic households.

Households with children under 18 purchase 13% less processed cheese than households without children under 18. Households with at least high school education level purchase 15% less processed cheese than households with less than high school education.

The elasticity of demand of processed cheese with respect to the age of household head is 0.18, which means that older household heads purchase more processed cheese than younger household heads.

The own-price elasticity of processed cheese is -0.68. The cross-price elasticity of processed cheese with respect to conventional milk is negative, which means that conventional milk is complement to processed cheese. The cross-price elasticity of processed cheese with respect to natural cheese is positive, which means that processed cheese is a substitute to processed cheese. The cross-price elasticity of processed cheese with respect to the weighted alternative category is negative, which means the products in other dairy categories are complements to processed cheese. The income elasticity of processed cheese is -0.06, which means processed cheese is an inferior good.

The elasticity of coupon value for processed cheese is 0.05, which means that a 1% increase in coupon value would lead to a 0.05% increase in the purchase of processed cheese, holding other factors constant.

Model 10 Greek yogurt

The significant variables include household size, household income, education, region, race, inverse Mills ratio, price of Greek yogurt, price of non-Greek yogurt, price of ice cream, price of conventional milk, price of weighted alternative for Greek yogurt, and coupon value.

Households located in the New England region purchase the most Greek yogurt compared to households located in other regions. Households in the East South Central and the West South

Central regions buy 43% and 33% less than households located in the New England region respectively.

White households purchase the most Greek yogurt compared to all the other races. Black households buy the least Greek yogurt, which is 35% less than white households. Asian and other households buy less Greek yogurt than white households, by 30% and 9% respectively. Hispanic households purchase 3% less Greek yogurt compared to non-Hispanic households.

Households with children under 18 purchase 1% less Greek yogurt than households without children under 18. Households with at least high school education level purchase 25% more Greek yogurt than households with less than high school education.

The elasticity of demand of Greek yogurt with respect to the age of the household head is -0.14, which means that older household heads purchase less Greek yogurt than younger household head.

The own-price elasticity of Greek yogurt is -1.54. The cross-price elasticities of Greek yogurt with respect to non-Greek yogurt, conventional milk and ice cream are all positive, which means that these products are substitutes to Greek yogurt. The cross-price elasticity of Greek yogurt with respect to the weighted alternative category is positive, which means the products in other dairy categories are substitutes to Greek yogurt. The income elasticity of Greek yogurt is 0.25, indicating that Greek yogurt is a necessity.

The elasticity of coupon value for Greek yogurt is 0.12, which means that a 1% increase in coupon value would increase the purchase of Greek yogurt by 0.12%, holding other factors constant.

Model 11 non-Greek yogurt

The significant variables include household size, household income, age, education, region, race, presence of children, inverse Mills ratio, price of Greek yogurt, price of non-Greek yogurt, price of conventional milk, and coupon value.

Households located in the New England region purchase the most Greek yogurt compared to households located in other regions. Households in the East South Central and the West South Central regions purchase 27% and 16% less non-Greek yogurt than households located in the New England region respectively

White households buy the most non-Greek yogurt compared to all the other races. Black households purchase the least non-Greek yogurt, which is 26% less than white households. Asian and other households buy less non-Greek yogurt than white households, by 17% and 8% respectively. Hispanic households purchase 6% more non-Greek yogurt than non-Hispanic households.

Households with children under 18 purchase 54% more non-Greek yogurt than households without children under 18. Households with at least high school education level purchase 15% more non-Greek yogurt than households with less than high school education.

The elasticity of demand of non-Greek yogurt with respect to the age of the household head is -0.14, which means older household heads purchase less non-Greek yogurt than younger household heads.

The own-price elasticity of non-Greek yogurt is -1.11. The cross-price elasticities of non-Greek yogurt with respect to Greek yogurt, conventional milk and ice cream are all negative, which means that these products are complements to non-Greek yogurt. The cross-price elasticity of non-Greek yogurt with respect to the weighted alternative category is negative, which means the products in other dairy categories are complements to non-Greek yogurt. The income elasticity of non-Greek yogurt is 0.05, indicating that non-Greek yogurt is a necessity.

The elasticity of coupon value for non-Greek yogurt is 0.07, which means that a 1% increase in coupon value would increase the purchase of non-Greek yogurt by 0.07%, holding other factors constant.

Model 12 Butter

The significant variables include household size, household income, age, education, region, race, ethnicity, presence of children, inverse Mills ratio, price of Butter, price of margarine, price of weighted alternative for butter, and coupon value.

Households located in the West North Central region purchase 4% more butter compared to households located in the New England region. Households located in other regions buy less butter compared to households in the New England region. Households in the East South Central region, purchase less butter than do households located in the New England region by 24%.

White households purchase the most butter compared to all the other races. Asian households buy the least butter, which is 39% less than white households. Black and other households purchase less butter than white households, by 31% and 10% respectively. Hispanic households buy 24% less butter than do non-Hispanic households.

Households with children under 18 purchase 12% less butter than households without children under 18. Households with at least high school education level purchase 4% more butter than households do with less than high school education.

The elasticity of demand of butter with respect to the age of the household head is 0.69, which means older household heads purchase more butter than younger household heads.

The own-price elasticity of butter is -0.61. The cross-price elasticity of butter with respect to margarine is positive, which means that margarine is substitute to butter. The cross-price elasticity of butter with respect to the weighted alternative category is positive, which means the products in other dairy categories are substitutes to butter. The income elasticity of butter is 0.07, indicating that butter is a necessity.

The elasticity of coupon value for butter is 0.03, which means that a 1% increase in coupon value would increase the purchase of butter by 0.03%, holding other factors constant.

Model 13 Margarine

The significant variables include household size, household income, age, education, region, race, ethnicity, presence of children, inverse Mills ratio, price of Butter, price of margarine, price of weighted alternative for margarine, and coupon value.

Households located in the East South Central region purchase 5% more margarine compared to households located in the New England region. Households located in other regions buy less margarine compared to households located in the New England region. Households in the Mountain and Pacific regions purchase 22% less than households located in the New England region.

Black households purchase the most margarine compared to all the other races, 1% more than white households. Asian households buy the least margarine, 42% less than white households. Other households purchase 2% less margarine than white households. Hispanic households buy 6% less margarine than do non-Hispanic households.

Households with children under 18 buy 20% less margarine than households without children under 18. Households with at least high school education level consume 21% less margarine than households with less than high school education.

The elasticity of demand of margarine with respect to the age of household head is 0.64, which means that older household heads purchase more margarine than the younger household heads.

The own-price elasticity of margarine is -0.77. The cross-price elasticity of margarine with respect to butter is positive, which means that butter is substitute to margarine. The cross-price elasticity of margarine with respect to the weighted alternative category is negative, which means the products in other dairy categories are complements to margarine. The income elasticity of margarine is -0.20, indicating that margarine is an inferior good.

The elasticity of coupon value for margarine is 0.06, which means that a 1% increase in coupon value would increase the purchase of margarine by 0.06%, holding other factors constant.

Comparison with Extant Literature

In Table II-14, we compare models, data, dairy products, uncompensated own-price elasticities, and income or expenditure elasticities with other studies in the extant literature. Similar to most cross-sectional studies, the own-price elasticities for most dairy products from our study are elastic, which is considered as a long-run depiction of the dairy sector. One difference from most previous studies is that conventional milk products have relatively more elastic own-price elasticities compared to other dairy products. At the same time, organic milk and plant-based milk alternatives have relatively less elastic own-price elasticities among fluid milk products. One explanation might be that households have more loyalty to organic milk and plant-based milk alternatives due to particular characteristics of these products, such as quality, flavor, organic production process, and free of lactose. Meanwhile, the fact that a number of competitors to conventional milk have entered the dairy market, which in turn lead to greater sensitivity of the price changes of conventional milk. Negative income elasticities have been found for some dairy products, including whole milk, margarine, ice cream, and processed cheese. Although this result is different from previous studies, these findings seem to be in accordance with the recent consumption trends. These products have disadvantages from quality or health aspects based on the trending social consensus.

Concluding Remarks

The changes in the demand for dairy products in recent decades have been a major concern to stakeholders in the dairy industry. A wider array of dairy products and more dairy alternative products have been offered to US consumers. In this study, the demands of a granular array of thirteen dairy products are investigated based on cross-sectional data from Nielsen Homescan Panel data for the calendar year 2015. Because of zero purchases, the Heckman two-step procedure is used to deal with the censoring problem. Elasticities and household socio-demographic effects are obtained from this research.

The own-price elasticities among the thirteen dairy products, plant-based milk alternatives, flavored milk, low-fat milk, skim milk, whole milk, natural cheese, Greek yogurt, and non-Greek yogurt are in the elastic range, while own-price elasticities for ice cream, processed cheese, butter, and margarine hare in the inelastic range. The own-price elasticity for organic milk is unitary elastic. The income elasticities of plant-based milk alternatives, flavored milk, organic milk, low-fat milk, skim milk, natural cheese, Greek yogurt, non-Greek yogurt, and butter are positive and below unity, meaning that they are necessities. At the same time, the income elasticities of whole milk, ice cream, processed cheese, and margarine have negative income elasticities, meaning that they are inferior goods. Based on cross-price elasticities, most products in the fluid milk category are substitutes to each other, except that flavored milk is a complement to low-fat milk and skim milk and organic milk is a complement to skim milk. For the yogurt category, ice cream and conventional milk are substitutes to Greek yogurt but complements to non-Greek yogurt. Non-Greek yogurt is a substitute for Greek yogurt, but not vice versa. For the cheese category, natural cheese and processed cheese are substitutes. Conventional milk is a complement to both cheese products. Further, butter and margarine are substitutes.

Region is a significant factor affecting the demand for most dairy products. Besides, race is a significant factor affecting the demand for all thirteen dairy products. Households with at least high school education purchase more plant-based milk alternatives, organic milk, skim milk, natural cheese, Greek yogurt, non-Greek yogurt, and butter, and less flavored milk, low-fat milk, whole milk, ice cream, processed cheese, and margarine, compared to household heads with less than high school education. Younger household heads purchase more plant-based milk alternatives, organic milk, whole milk, natural cheese, Greek yogurt, and non-Greek yogurt, but less flavored milk, skim milk, low-fat milk, processed cheese, ice cream, butter, and margarine, than older household heads. The presence of children also affects the demand for different dairy products. More flavored milk, organic milk, low-fat milk, whole milk, and non-Greek yogurt, but less plant-based milk alternatives, skim milk, ice cream, Greek yogurt, natural cheese, processed cheese, butter, and margarine are purchased by households with children under eighteen compared to households without children under eighteen. From our findings, coupon values have significant effects on promoting the demand for all dairy products. Thus, this study supports confidence in the use of coupons to promote dairy products.

In the recent decade, agribusinesses in the dairy market have already made responses according to the changes in the dairy market. Dallas-based Dean Foods, the largest milk processor in the United States, has filed for Chapter 11 bankruptcy protection in November of 2019 (Dallas Business Journal, Nov 12, 2019). Soon after, another world wild food processor, General Mills launched the first nondairy yogurt (StarTribune.com, Dec 3, 2019). Thus, research based on more current dairy market information is needed for stakeholders to develop their market strategies. Although, our work is based on Nielsen Homescan panel data for the calendar year 2015, a foundation built on which to analyze for a granular array of dairy products. Without question, updated data to check on the robustness of our findings are needed.

Another limitation of this study is that the significance level of the elasticities and marginal effects of socio-demographic factors on demands are not specified in our work. Bootstrapping method or delta method could be used to mitigate this issue. In addition, while our work using the single-equation demand models is more flexible and faces less computational difficulties in estimation, we failed to capture the interrelationships among different dairy demands systematically. Thus demand system analyses are warranted for future studies to hand this situation.

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Table II-1 Continuous Variables

Quantity (ounces)	Price ($/ ounce)	Expenditure ($)	Coupon Value ($)	Income ($)	Household Size	Household head Age
Flavored Milk	Flavored Milk	Flavored Milk	Flavored Milk	Household income corresponds to the use of midpoints of various intervals from the 2015 Nielsen Homescan data.	1-9+ Members	Household head age corresponds to the use of midpoints of various intervals from the 2015 Nielsen Homescan data.
Organic Milk	Organic Milk	Organic Milk	Organic Milk			
Skim Milk	Skim Milk	Skim Milk	Skim Milk			
Whole Milk	Whole Milk	Whole Milk	Whole Milk			
Low-fat Milk	Low-fat Milk	Low-fat Milk	Low-fat Milk			
Plant-based Milk Alternatives	Plant-based Milk Alternatives	Plant-based Milk Alternatives	Plant-based Milk Alternatives			
Butter	Butter	Butter	Butter			
Margarine	Margarine	Margarine	Margarine			
Ice Cream	Ice Cream	Ice Cream	Ice Cream			
Natural Cheese	Natural Cheese	Natural Cheese	Natural Cheese			
Processed Cheese	Processed Cheese	Processed Cheese	Processed Cheese			
Non-Greek Yogurt	Non-Greek Yogurt	Non-Greek Yogurt	Non-Greek Yogurt			
Greek Yogurt	Greek Yogurt	Greek Yogurt	Greek Yogurt			

Table II-2 Binary Variables

Region[5]	Race	Ethnicity	Education	Presence of Children	Coupon Use
New England	*White/Caucasian*	*not Hispanic*	*Some High School or less*	*No Children Under 18*	*did not use coupon*
Middle Atlantic					
East North Central	Black/African American				
West North Central					
South Atlantic					
East South Central	Asian	Hispanic	Graduated High School or higher	Children Under 18	used coupon
West South Central					
Mountain	Other				
Pacific					

*Base or reference categories are in italics

[5] The states associated with the regions are shown in Appendix A.1.

Table II-3 Summary Statistics on Quantity, Expenditure, Price (Unit Value), and Coupon Value, Conditional on Purchases

Quantity (ounces)						
Products	**No. of Obs.**	**Mean**	**Std. Dev**	**Min**	**Max**	**Proportion of Obs.**
Flavored Milk	14,253	428.18	968.86	8.00	40,457.40	23%
Organic Milk	4,623	971.94	1,503.19	32.00	22,656.00	8%
Skim Milk	14,848	1,633.41	2,521.04	8.00	67,328.00	24%
Whole Milk	24,324	1,217.40	2,082.88	8.00	66,432.00	40%
Low-fat Milk	45,483	2,061.32	2,731.48	8.00	44,672.00	74%
Plant-based Milk Alternatives	13,288	383.47	644.01	8.00	12,160.00	22%
Butter	43,811	141.16	157.45	2.00	3,424.00	71%
Margarine	37,193	170.65	266.19	1.98	17,854.02	61%
Ice Cream	43,551	374.60	543.05	5.80	10,848.00	71%
Natural Cheese	58,865	379.58	396.32	1.00	6,825.00	96%
Processed Cheese	52,845	127.99	141.71	1.00	4,092.00	86%
Non-Greek Yogurt	44,705	336.14	481.91	3.50	10,048.00	73%
Greek Yogurt	32,953	221.06	356.94	3.50	8,654.90	54%
Expenditure ($)						
Products	**No. of Obs.**	**Mean**	**Std. Dev**	**Min**	**Max**	**Proportion of Obs.**
Flavored Milk	14,253	16.10	34.23	0.15	837.38	23%
Organic Milk	4,623	56.71	85.31	1.00	1,196.33	8%
Skim Milk	14,848	38.84	56.20	0.29	1,456.72	24%
Whole Milk	24,324	33.05	53.48	0.31	2,029.88	40%
Low-fat Milk	45,483	52.77	65.62	0.25	1,066.77	74%
Plant-based Milk Alternatives	13,288	19.86	32.94	0.50	589.28	22%
Butter	43,811	32.21	34.77	0.29	568.31	71%
Margarine	37,193	15.78	17.35	0.25	478.54	61%
Ice Cream	43,551	26.60	35.88	0.23	847.37	71%
Natural Cheese	58,865	99.37	93.15	0.37	1,427.72	96%
Processed Cheese	52,845	29.21	31.29	0.25	1,226.22	86%
Non-Greek Yogurt	44,705	35.70	51.83	0.18	2,120.73	73%
Greek Yogurt	32,953	39.65	63.83	0.20	1,446.36	54%

Table II-3 Continued

Price ($/ounce)					
Products	**No. of Observations**	**Mean**	**Std. Dev**	**Min**	**Max**
Flavored Milk	14,253	0.05	0.03	0.003	0.19
Organic Milk	4,623	0.06	0.01	0.016	0.13
Skim Milk	14,848	0.03	0.01	0.008	0.09
Whole Milk	24,324	0.03	0.02	0.007	0.11
Low-fat Milk	45,483	0.03	0.01	0.005	0.10
Plant-based Milk Alternatives	13,288	0.05	0.02	0.015	0.14
Butter	43,811	0.25	0.09	0.023	0.72
Margarine	37,193	0.12	0.06	0.002	0.43
Ice Cream	43,551	0.09	0.06	0.005	0.41
Natural Cheese	58,865	0.29	0.10	0.030	0.77
Processed Cheese	52,845	0.25	0.08	0.031	0.66
Non-Greek Yogurt	44,705	0.12	0.06	0.018	0.43
Greek Yogurt	32,953	0.19	0.07	0.006	0.52
Coupon Value ($)					
Products	**No. of Observations**	**Mean**	**Std. Dev**	**Min**	**Max**
Flavored Milk	14,253	0.41	2.52	0.00	93.86
Organic Milk	4,623	0.28	2.03	0.00	70.00
Skim Milk	14,848	0.63	3.41	0.00	147.44
Whole Milk	24,324	0.37	2.70	0.00	127.06
Low-fat Milk	45,483	0.78	4.28	0.00	222.68
Plant-based Milk Alternatives	13,288	0.94	3.02	0.00	94.87
Butter	43,811	0.69	2.56	0.00	84.71
Margarine	37,193	0.55	1.97	0.00	53.68
Ice Cream	43,551	0.95	3.56	0.00	120.70
Natural Cheese	58,865	2.34	7.28	0.00	232.91
Processed Cheese	52,845	0.71	2.49	0.00	99.89
Non-Greek Yogurt	44,705	1.18	4.10	0.00	124.75
Greek Yogurt	32,953	1.70	5.28	0.00	161.55

Table II-3 Continued

Coupon Use (binary)		
Products	**No. of Observations**	**Mean**
Flavored Milk	1,725	0.03
Organic Milk	368	0.01
Skim Milk	1,983	0.03
Whole Milk	2,296	0.04
Low-fat Milk	7,121	0.12
Plant-based Milk Alternatives	3,721	0.06
Butter	8,559	0.14
Margarine	7,392	0.12
Ice Cream	9,602	0.16
Natural Cheese	21,072	0.34
Processed Cheese	11,693	0.19
Non-Greek Yogurt	12,205	0.20
Greek Yogurt	10,727	0.17

Table II-4 Summary Statistics for the Respective Socio-demographic Variables

Variable	No. of Observations	Mean
New England	61,380	0.05
Middle Atlantic	61,380	0.13
East North Central	61,380	0.18
West North Central	61,380	0.08
South Atlantic	61,380	0.20
East South Central	61,380	0.06
West South Central	61,380	0.10
Mountain	61,380	0.07
Pacific	61,380	0.12
White	61,380	0.82
Black	61,380	0.11
Asian	61,380	0.03
Other	61,380	0.05
Ethnicity[6]	61,380	0.06
Education[7]	61,380	0.81
Presence of Children	61,380	0.22

Table II-4 Continued

Variable	No. of Observations	Mean	Std. Dev	Min	Max
Household Size	61,380	2.38	1.30	1	9
Household Head Age	61,380	54	11	22	65
Household Income($)	61,380	58,488	29,235	2,500	100,000

[6] Reference category: non-Hispanic
[7] Reference category: Less than high school education

Table II-5 Summary Statistics of Observed, Imputed Prices, and Market Penetration for 2015 for Dairy Products

	Observed Price ($/ounce)		Imputed Price ($/ounce)		Market penetration
Products	**No. of Obs.**	**Mean**	**No. of Obs.**	**Mean**	
Flavored Milk	14,278	0.05	61,380	0.05	23%
Organic Milk	4,625	0.06	61,380	0.06	8%
Skim Milk	14,849	0.03	61,380	0.03	24%
Whole Milk	24,331	0.03	61,380	0.03	40%
Low-fat Milk	45,493	0.03	61,380	0.03	74%
Plant-based Milk Alternatives	13,288	0.05	61,380	0.05	29%
Butter	43,813	0.25	61,380	0.23	71%
Margarine	37,197	0.12	61,380	0.10	61%
Ice Cream	43,564	0.09	61,380	0.08	71%
Natural Cheese	58,865	0.29	61,380	0.28	96%
Processed Cheese	52,850	0.25	61,380	0.23	86%
Non-Greek Yogurt	44,716	0.12	61,380	0.11	73%
Greek Yogurt	32,968	0.19	61,380	0.18	54%

Table II-6 Percentage of Household Who Buy Milk, Yogurt, and Cheese in Calendar Year 2015

Organic and Conventional Milk	
Organic Milk Only	2%
Conventional Milk Only	84%
Both Organic and Conventional Milk	6%
Plant-based Milk Alternative and Conventional Milk	
Plant-based Milk Alternative (PMA) Only	3%
Conventional Milk Only	72%
Both PMA and Conventional Milk	18%
Yogurt	
non-Greek Yogurt Only	28%
Greek Yogurt Only	9%
Both non-Greek and Greek yogurt	45%
Cheese	
Natural Cheese	2%
Processed Cheese	12%
Both Processed and Natural Cheese	84%

Table II-7 Alternative Specifications for the Respective Probit Model for Different Dairy Products

	Specific Alternatives					Weighted Alternative Category (WAC[8])						
Flavored Milk	Conventional White Milk	Organic Milk	PMA			Butter	Cheese	Yogurt	Ice Cream			
Organic Milk	Conventional White Milk	Flavored Milk	PMA			Butter	Cheese	Yogurt	Ice Cream			
Skim Milk	Low-fat Milk	Flavored Milk	Organic Milk	PMA	Whole Milk	Butter	Cheese	Yogurt	Ice Cream			
Whole Milk	Low-fat Milk	Flavored Milk	Organic Milk	PMA	Skim Milk	Butter	Cheese	Yogurt	Ice Cream			
Low-fat Milk	Whole Milk	Flavored Milk	Organic Milk	PMA	Skim Milk	Butter	Cheese	Yogurt	Ice Cream			
PMA[9]	Conventional White Milk	Flavored Milk	Organic Milk			Butter	Cheese	Yogurt	Ice Cream			
Butter	Margarine					Yogurt	Cheese	PMA	Ice Cream	Organic Milk	Conventional White Milk	Flavored Milk
Margarine	Butter					Yogurt	Cheese	PMA	Ice Cream	Organic Milk	Conventional White Milk	Flavored Milk
Ice Cream	Non-Greek Yogurt	Greek Yogurt				Butter	Cheese	PMA	Ice Cream	Organic Milk	Conventional White Milk	Flavored Milk
Natural Cheese	Conventional White Milk	Processed Cheese				Butter	Cheese	Yogurt	Ice Cream	Organic Milk	PMA	Flavored Milk
Processed Cheese	Conventional White Milk	Natural Cheese				Butter	Cheese	Yogurt	Ice Cream	Organic Milk	PMA	Flavored Milk
Non-Greek Yogurt	Conventional White Milk	Greek Yogurt	Ice Cream			Butter	Cheese	PMA	Organic Milk	Flavored Milk		
Greek Yogurt	Conventional White Milk	Non-Greek Yogurt	Ice Cream			Butter	Cheese	PMA	Organic Milk	Flavored Milk		

[8] Represents categories used to calculated weighed average price of the remaining dairy products

[9] Short for plant-based milk alternatives

Table II-8 Empirical Results of Probit Models for Different Dairy Products

PMA			Flavored Milk			Organic Milk		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**2.46**	**0.00**	Intercept	0.60	0.11	Intercept	0.68	0.08
log(household size)	**0.19**[10]	**0.00**	log(household size)	**0.36**	**0.00**	log(household size)	0.01	0.52
log(income)	0.01	0.14	log(income)	**-0.05**	**0.00**	log(income)	**0.18**	**0.00**
log(age)	**-0.24**	**0.00**	log(age)	**-0.24**	**0.00**	log(age)	**-0.30**	**0.00**
Education	**0.15**	**0.00**	Education	**-0.12**	**0.00**	Education	**0.25**	**0.00**
Middle Atlantic	**-0.11**	**0.00**	Middle Atlantic	**0.13**	**0.00**	Middle Atlantic	**0.09**	**0.03**
East North Central	**-0.11**	**0.00**	East North Central	**0.46**	**0.00**	East North Central	0.07	0.11
West North Central	**-0.17**	**0.00**	West North Central	**0.55**	**0.00**	West North Central	-0.10	0.05
South Atlantic	**-0.10**	**0.00**	South Atlantic	**0.15**	**0.00**	South Atlantic	0.07	0.09
East South Central	**-0.12**	**0.00**	East South Central	**0.41**	**0.00**	East South Central	0.07	0.19
West South Central	**-0.10**	**0.01**	West South Central	**0.31**	**0.00**	West South Central	**0.27**	**0.00**
Mountain	**0.14**	**0.00**	Mountain	**0.24**	**0.00**	Mountain	**0.33**	**0.00**
Pacific	0.03	0.40	Pacific	0.01	0.86	Pacific	**0.23**	**0.00**
Black/ African American	**0.21**	**0.00**	Black/ African American	**-0.26**	**0.00**	Black/ African American	**-0.21**	**0.00**
Asian	**0.09**	**0.01**	Asian	**-0.25**	**0.00**	Asian	**0.30**	**0.00**
Other	**0.10**	**0.00**	Other	-0.05	0.11	Other	0.05	0.21
Hispanic	**0.07**	**0.01**	Hispanic	**-0.08**	**0.01**	Hispanic	0.04	0.21
Presence of Children	**-0.07**	**0.00**	Presence of Children	**0.08**	**0.00**	Presence of Children	**0.19**	**0.00**
log(Price of PMA)	**0.26**	**0.00**	log(Price of Flavored Milk)	**0.11**	**0.00**	log(Price of Organic Milk)	-0.13	0.08
log(Price of Conventional Milk)	**0.32**	**0.00**	log(Price of PMA)	0.09	0.09	log(Price of Flavored Milk)	**0.29**	**0.00**
log(Price of Organic Milk)	0.09	0.37	log(Price of Conventional Milk)	**-0.07**	**0.00**	log(Price of Conventional Milk)	**0.56**	**0.00**
log(Price of Flavored Milk)	**0.11**	**0.00**	log(Price of Organic Milk)	0.07	0.48	log(Price of PMA)	0.08	0.25
log(Price of WAC for PMA)	**0.21**	**0.00**	log(Price of WAC for Flavored Milk)	**-0.12**	**0.00**	log(Price of WAC for Organic Milk)	**0.40**	**0.00**
Coupon Use for PMA	**8.91**	**0.00**	Coupon Use for Flavored Milk	**5.33**	**0.04**	Coupon Use for Organic Milk	**9.00**	**0.00**

Note: numbers in bold are significant at the 5% significant level

[10] The marginal effect of probit model is calculated as $\alpha_i \phi(Z'_{ih}\alpha_i)$, where α_i is the estimated parameter and $\phi(Z'_{ih}\alpha_i)$ is the standard normal distribution pdf at $Z'_{ih}\alpha_i$ (see Appendix A.3)

Table II-8 Continued

Low-fat Milk			Skim Milk			Whole Milk		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**-0.89**	**0.02**	Intercept	**-3.60**	**0.00**	Intercept	**3.96**	**0.00**
log(household size)	**0.38**	**0.00**	log(household size)	0.02	0.28	log(household size)	**0.31**	**0.00**
log(income)	**0.04**	**0.00**	log(income)	**0.16**	**0.00**	log(income)	**-0.15**	**0.00**
log(age)	**0.11**	**0.00**	log(age)	0.04	0.14	log(age)	**-0.11**	**0.00**
Education	**-0.05**	**0.00**	Education	**0.13**	**0.00**	Education	**-0.19**	**0.00**
Middle Atlantic	**-0.07**	**0.03**	Middle Atlantic	**0.26**	**0.00**	Middle Atlantic	**-0.06**	**0.02**
East North Central	0.03	0.33	East North Central	**0.20**	**0.00**	East North Central	**-0.14**	**0.00**
West North Central	-0.01	0.83	West North Central	**0.35**	**0.00**	West North Central	**-0.21**	**0.00**
South Atlantic	**-0.10**	**0.00**	South Atlantic	**0.06**	**0.05**	South Atlantic	0.01	0.59
East South Central	0.01	0.89	East South Central	**0.08**	**0.02**	East South Central	**0.09**	**0.01**
West South Central	**-0.09**	**0.01**	West South Central	-0.04	0.26	West South Central	**0.14**	**0.00**
Mountain	0.04	0.26	Mountain	-0.05	0.15	Mountain	0.03	0.43
Pacific	**-0.10**	**0.00**	Pacific	**-0.08**	**0.01**	Pacific	**-0.12**	**0.00**
Black/ African American	**-0.25**	**0.00**	Black/ African American	**-0.48**	**0.00**	Black/ African American	**0.24**	**0.00**
Asian	**-0.32**	**0.00**	Asian	**-0.19**	**0.00**	Asian	0.00	0.89
Other	**-0.14**	**0.00**	Other	**-0.19**	**0.00**	Other	**0.07**	**0.01**
Hispanic	0.02	0.36	Hispanic	0.00	**0.00**	Hispanic	0.02	0.46
Presence of Children	0.00	0.89	Presence of Children	**-0.04**	**0.05**	Presence of Children	**-0.04**	**0.02**
log(Price of Low-fat Milk)	**0.17**	**0.00**	log(Price of Skim Milk)	**0.22**	**0.00**	log(Price of Whole Milk)	**0.05**	**0.02**
log(Price of Whole Milk)	-0.02	0.39	log(Price of Organic Milk)	**-0.46**	**0.00**	log(Price of Organic Milk)	0.05	0.54
log(Price of Skim Milk)	**0.15**	**0.00**	log(Price of Low-fat Milk)	-0.02	0.27	log(Price of Low-fat Milk)	**0.12**	**0.00**
log(Price of Flavored Milk)	**-0.13**	**0.00**	log(Price of Whole Milk)	**0.19**	**0.00**	log(Price of Skim Milk)	**0.28**	**0.00**
log(Price of Organic Milk)	-0.05	0.37	log(Price of Flavored Milk)	**-0.08**	**0.00**	log(Price of Flavored Milk)	**0.11**	**0.00**
log(Price of PMA)	-0.17	0.08	log(Price of PMA)	-0.11	0.05	log(Price of PMA)	0.06	0.20
log(Price of WAC for Low-fat Milk)	**-0.28**	**0.00**	log(Price of WAC for Skim Milk)	**-0.14**	**0.00**	log(Price of WAC for Whole Milk)	-0.01	0.41
Coupon Use for Low-fat Milk	**20.40**	**0.00**	Coupon Use for Skim Milk	**19.21**	**0.00**	Coupon Use for Whole Milk	**11.65**	**0.00**

Table II-8 Continued

Ice Cream			Natural Cheese			Processed Cheese		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	-0.13	0.44	Intercept	**1.72**	**0.00**	Intercept	0.04	0.84
log(household size)	**0.37**	**0.00**	log(household size)	**0.61**	**0.00**	log(household size)	**0.61**	**0.00**
log(income)	**-0.07**	**0.00**	log(income)	**0.06**	**0.00**	log(income)	-0.01	**0.00**
log(age)	**0.15**	**0.00**	log(age)	**-0.20**	**0.00**	log(age)	**0.10**	**0.00**
Education	**-0.06**	**0.00**	Education	0.01	0.68	Education	**-0.15**	**0.00**
Middle Atlantic	**-0.09**	**0.00**	Middle Atlantic	-0.08	0.21	Middle Atlantic	-0.03	0.45
East North Central	**0.09**	**0.00**	East North Central	0.08	0.20	East North Central	**0.14**	**0.00**
West North Central	**0.09**	**0.01**	West North Central	0.07	0.33	West North Central	**0.23**	**0.00**
South Atlantic	**0.07**	**0.02**	South Atlantic	0.03	0.57	South Atlantic	**0.08**	**0.02**
East South Central	**0.17**	**0.00**	East South Central	0.01	0.92	East South Central	**0.30**	**0.00**
West South Central	**0.18**	**0.00**	West South Central	-0.02	0.77	West South Central	**0.12**	**0.00**
Mountain	**0.08**	**0.03**	Mountain	0.11	0.13	Mountain	-0.03	0.45
Pacific	0.01	0.77	Pacific	0.00	0.99	Pacific	**-0.19**	**0.00**
Black/ African American	**-0.12**	**0.00**	Black/ African American	**-0.32**	**0.00**	Black/ African American	**-0.35**	**0.00**
Asian	**-0.29**	**0.00**	Asian	**-0.81**	**0.00**	Asian	**-0.53**	**0.00**
Other	-0.05	0.11	Other	-0.07	0.21	Other	**-0.14**	**0.00**
Hispanic	**-0.08**	**0.00**	Hispanic	-0.05	0.37	Hispanic	**-0.08**	**0.01**
Presence of Children	-0.03	0.10	Presence of Children	**-0.09**	**0.04**	Presence of Children	**-0.11**	**0.00**
log(Price of Ice Cream)	-0.002	0.85	log(Price of Natural Cheese)	-0.05	0.20	log(Price of Processed Cheese)	**0.06**	**0.03**
log(Price of Greek Yogurt)	0.05	0.20	log(Price of Processed Cheese)	0.02	0.62	log(Price of Natural Cheese)	-0.02	0.39
log(Price of non-Greek Yogurt)	**-0.08**	**0.00**	log(Price of Conventional Milk)	**-0.07**	**0.04**	log(Price of Conventional Milk)	**-0.14**	**0.00**
log(Price of WAC for Ice Cream)	**-0.13**	**0.00**	log(Price of WAC for Natural Cheese)	**0.21**	**0.00**	log(Price of WAC for Processed Cheese)	-0.03	0.06
Coupon Use for Ice Cream	**8.88**	**0.00**	Coupon Use for Natural Cheese	4.87	0.95	Coupon Use for Processed Cheese	5.54	0.96

Table II-8 Continued

Greek Yogurt			non-Greek Yogurt		
	Estimate	p-Value		Estimate	p-Value
Intercept	**0.47**	**0.01**	Intercept	0.05	0.78
log(household size)	**0.19**	**0.00**	log(household size)	**0.32**	**0.00**
log(income)	0.13	1.00	log(income)	0.02	0.06
log(age)	**-0.19**	**0.00**	log(age)	**-0.22**	**0.00**
Education	0.16	1.00	Education	**0.08**	**0.00**
Middle Atlantic	**-0.08**	**0.01**	Middle Atlantic	-0.06	0.09
East North Central	**-0.09**	**0.00**	East North Central	0.00	0.94
West North Central	-0.06	0.09	West North Central	0.02	0.65
South Atlantic	**-0.13**	**0.00**	South Atlantic	-0.06	0.06
East South Central	**-0.19**	**0.00**	East South Central	**-0.10**	**0.00**
West South Central	**-0.14**	**0.00**	West South Central	-0.03	0.37
Mountain	0.01	0.79	Mountain	-0.01	0.72
Pacific	**-0.07**	**0.03**	Pacific	-0.01	0.82
Black/ African American	**-0.23**	**0.00**	Black/ African American	**-0.14**	**0.00**
Asian	**-0.20**	**0.00**	Asian	**-0.12**	**0.00**
Other	-0.05	0.07	Other	**-0.07**	**0.03**
Hispanic	0.03	0.27	Hispanic	**0.06**	**0.04**
Presence of Children	0.01	0.69	Presence of Children	**0.26**	**0.00**
log(Price of Greek Yogurt)	**-0.47**	**0.00**	log(Price of non-Greek Yogurt)	**-0.11**	**0.00**
log(Price of non-Greek Yogurt)	**0.55**	**0.00**	log(Price of Greek Yogurt)	-0.06	0.13
log(Price of Ice Cream)	**0.22**	**0.00**	log(Price of Ice Cream)	-0.02	0.15
log(Price of Conventional Milk)	**0.14**	**0.00**	log(Price of Conventional Milk)	**-0.08**	**0.00**
log(Price of WAC for Greek Yogurt)	**-0.04**	**0.00**	log(Price of WAC for non-Greek Yogurt)	**-0.06**	**0.00**
Coupon Use for Greek Yogurt	6.78	0.97	Coupon Use for non-Greek Yogurt	**7.50**	**0.00**

Table II-8 Continued

Butter			Margarine		
	Estimate	p-Value		Estimate	p-Value
Intercept	**-1.98**	**0.00**	Intercept	-0.03	0.86
log(household size)	**0.31**	**0.00**	log(household size)	**0.35**	**0.00**
log(income)	**0.15**	**0.00**	log(income)	**-0.15**	**0.00**
log(age)	**0.46**	**0.00**	log(age)	**0.16**	**0.00**
Education	**0.16**	**0.00**	Education	**-0.22**	**0.00**
Middle Atlantic	-0.01	0.76	Middle Atlantic	**-0.06**	**0.03**
East North Central	-0.04	0.22	East North Central	**0.09**	**0.00**
West North Central	0.01	0.67	West North Central	**0.09**	**0.00**
South Atlantic	**-0.13**	**0.00**	South Atlantic	**0.10**	**0.00**
East South Central	**-0.24**	**0.00**	East South Central	**0.29**	**0.00**
West South Central	**-0.16**	**0.00**	West South Central	**0.16**	**0.00**
Mountain	0.00	0.92	Mountain	**-0.14**	**0.00**
Pacific	**-0.07**	**0.03**	Pacific	**-0.15**	**0.00**
Black/ African American	**-0.27**	**0.00**	Black/ African American	**0.20**	**0.00**
Asian	**-0.31**	**0.00**	Asian	**-0.34**	**0.00**
Other	**-0.15**	**0.00**	Other	0.01	0.69
Hispanic	**-0.17**	**0.00**	Hispanic	**0.07**	**0.01**
Presence of Children	**-0.05**	**0.02**	Presence of Children	**-0.11**	**0.00**
log(Price of Butter)	0.04	0.06	log(Price of Margarine)	**-0.09**	**0.00**
log(Price of Margarine)	**0.29**	**0.00**	log(Price of Butter)	**-0.13**	**0.00**
log(Price of WAC for Butter)	**0.16**	**0.00**	log(Price of WAC for Margarine)	**-0.28**	**0.00**
Coupon Use for Butter	**9.22**	**0.00**	Coupon Use for Margarine	**10.35**	**0.00**

Table II-9 F-Tests for Region and Race, and McFadden's R^2 for the respective Probit Models

	F-test for region		F-test for race		**McFadden's** R^2
	Statistic	p-value	Statistic	p-value	
Plant-based Milk Alternatives	**158.85**	**0.00**	**115.35**	**0.00**	0.21
Flavored Milk	**737.13**	**0.00**	**188.48**	**0.00**	0.12
Organic Milk	**179.40**	**0.00**	**126.40**	**0.00**	0.13
Low-fat Milk	**68.91**	**0.00**	**280.02**	**0.00**	0.09
Skim Milk	**487.89**	**0.00**	**510.92**	**0.00**	0.11
Whole Milk	**283.91**	**0.00**	**192.85**	**0.00**	0.08
Butter	**162.60**	**0.00**	**307.47**	**0.00**	0.13
Margarine	**462.78**	**0.00**	**253.11**	**0.00**	0.14
Ice Cream	**166.96**	**0.00**	**114.98**	**0.00**	0.12
Natural Cheese	**19.54**	**0.01**	**345.95**	**0.00**	0.17
Processed Cheese	**320.49**	**0.00**	**496.55**	**0.00**	0.14
Greek Yogurt	**71.85**	**0.00**	**187.10**	**0.00**	0.22
Non-Greek Yogurt	**27.61**	**0.00**	**61.71**	**0.00**	0.16

Table II-10 Heteroscedasticity Test, Associated with the Heckman Procedure for Respective Dairy Products

	Estimate of $\widehat{\theta_\iota}$	p-Value
Plant-based Milk Alternatives	0.01	0.44
Flavored Milk	**-0.03**	**0.02**
Organic Milk	0.0006	0.94
Low-fat Milk	**0.16**	**0.00**
Skim Milk	**-0.11**	**0.00**
Whole Milk	**-0.09**	**0.00**
Butter	-0.03	0.07
Margarine	**-0.04**	**0.00**
Ice Cream	-0.02	0.56
Natural Cheese	**2.98**	**0.00**
Processed Cheese	**0.82**	**0.00**
Greek Yogurt	**-0.08**	**0.00**
Non-Greek Yogurt	**-0.42**	**0.00**

Table II-11 Empirical Results of the Respective Demand Models for Different Dairy Products

Plant-based Milk Alternatives			Flavored Milk			Organic Milk		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**2.28**	**0.00**	Intercept	**2.37**	**0.00**	Intercept	**3.71**	**0.00**
log(household size)	0.04	0.16	log(household size)	**0.15**	**0.00**	log(household size)	**0.15**	**0.01**
log(income)	0.02	0.12	log(income)	**0.05**	**0.00**	log(income)	**0.08**	**0.02**
log(age)	**0.12**	**0.01**	log(age)	**0.25**	**0.00**	log(age)	0.07	0.46
Education	0.02	0.49	Education	0.01	0.63	Education	0.05	0.50
Middle Atlantic	-0.03	0.51	Middle Atlantic	-0.05	0.44	Middle Atlantic	0.06	0.56
East North Central	**-0.14**	**0.00**	East North Central	0.01	0.80	East North Central	-0.03	0.79
West North Central	-0.05	0.41	West North Central	-0.01	0.82	West North Central	0.12	0.35
South Atlantic	**-0.11**	**0.01**	South Atlantic	-0.06	0.26	South Atlantic	0.06	0.55
East South Central	-0.09	0.09	East South Central	-0.06	0.37	East South Central	0.10	0.45
West South Central	**-0.13**	**0.01**	West South Central	0.02	0.71	West South Central	-0.07	0.52
Mountain	0.01	0.90	Mountain	0.08	0.24	Mountain	-0.09	0.43
Pacific	0.04	0.36	Pacific	-0.12	0.05	Pacific	-0.10	0.33
Black/African American	-0.04	0.20	Black/ African American	**-0.24**	**0.00**	Black/ African American	**-0.20**	**0.00**
Asian	0.08	0.10	Asian	-0.02	0.75	Asian	0.09	0.25
Other	0.08	0.07	Other	**-0.11**	**0.03**	Other	-0.02	0.82
Hispanic	**0.09**	**0.02**	Hispanic	-0.05	0.29	Hispanic	0.01	0.87
Presence of Children	0.00	0.96	Presence of Children	-0.01	0.87	Presence of Children	**0.25**	**0.00**
IMR	**-0.23**	**0.00**	IMR	**-0.30**	**0.00**	IMR	**-0.34**	**0.00**
log(Price of PMA)	**-1.34**	**0.00**	log(Price of Flavored Milk)	**-1.34**	**0.00**	log(Price of Organic Milk)	**-0.92**	**0.00**
log(Price of Conventional	**0.24**	**0.00**	log(Price of PMA)	**0.33**	**0.00**	log(Price of Flavored Milk)	**0.26**	**0.00**
log(Price of Organic Milk)	0.15	0.28	log(Price of Conventional Milk)	**0.46**	**0.00**	log(Price of Conventional Milk)	-0.11	0.06
log(Price of Flavored Milk)	0.02	0.61	log(Price of Organic Milk)	0.13	0.12	log(Price of PMA)	0.12	0.39
log(Price of WAC for PMA)	**0.16**	**0.00**	log(Price of WAC for Flavored	-0.06	0.06	log(Price of WAC for Organic	**0.23**	**0.00**
Coupon Value for PMA	**0.09**	**0.00**	Coupon Value for Flavored Milk	**0.06**	**0.00**	Coupon Value for Organic Milk	**0.05**	**0.00**

Table II-11 Continued

Low-fat Milk			Skim Milk			Whole Milk		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**5.38**	**0.00**	Intercept	**2.60**	**0.00**	Intercept	**3.57**	**0.00**
log(household size)	**0.37**	**0.00**	log(household size)	**0.34**	**0.00**	log(household size)	**0.31**	**0.00**
log(income)	**-0.08**	**0.00**	log(income)	-0.01	0.75	log(income)	**-0.10**	**0.00**
log(age)	**0.19**	**0.00**	log(age)	**0.39**	**0.00**	log(age)	-0.06	0.14
Education	-0.02	0.15	Education	0.02	0.45	Education	**-0.11**	**0.00**
Middle Atlantic	**-0.09**	**0.00**	Middle Atlantic	-0.01	0.93	Middle Atlantic	-0.05	0.26
East North Central	**-0.13**	**0.00**	East North Central	-0.04	0.54	East North Central	-0.09	0.06
West North Central	-0.06	0.07	West North Central	**0.26**	**0.00**	West North Central	0.04	0.46
South Atlantic	**-0.07**	**0.03**	South Atlantic	**0.18**	**0.00**	South Atlantic	0.02	0.58
East South Central	-0.07	0.06	East South Central	**0.18**	**0.01**	East South Central	0.07	0.18
West South Central	-0.06	0.10	West South Central	0.12	0.07	West South Central	-0.01	0.82
Mountain	**-0.12**	**0.00**	Mountain	-0.13	0.06	Mountain	-0.11	0.05
Pacific	-0.03	0.30	Pacific	**-0.17**	**0.01**	Pacific	0.01	0.79
Black/ African American	**-0.27**	**0.00**	Black/ African American	**-0.40**	**0.00**	Black/ African American	**-0.23**	**0.00**
Asian	-0.07	0.05	Asian	**-0.24**	**0.00**	Asian	0.00	0.94
Other	0.02	0.53	Other	-0.06	0.35	Other	-0.02	0.60
Hispanic	-0.03	0.21	Hispanic	-0.04	0.41	Hispanic	0.02	0.53
Presence of Children	**0.10**	**0.00**	Presence of Children	-0.01	0.86	Presence of Children	**0.08**	**0.01**
IMR	**-1.30**	**0.00**	IMR	**-0.52**	**0.00**	IMR	**-0.74**	**0.00**
log(Price of Low-fat Milk)	**-1.81**	**0.00**	log(Price of Skim Milk)	**-2.01**	**0.00**	log(Price of Whole Milk)	**-2.03**	**0.00**
log(Price of Whole Milk)	**0.29**	**0.00**	log(Price of Organic Milk)	**0.51**	**0.00**	log(Price of Organic Milk)	0.26	0.06
log(Price of Skim Milk)	**0.45**	**0.00**	log(Price of Low-fat Milk)	**0.14**	**0.00**	log(Price of Low-fat Milk)	**0.28**	**0.00**
log(Price of Flavored Milk)	**0.06**	**0.02**	log(Price of Whole Milk)	**0.35**	**0.00**	log(Price of Skim Milk)	**0.19**	**0.00**
log(Price of PMA)	**0.23**	**0.00**	log(Price of Flavored Milk)	**0.12**	**0.00**	log(Price of Flavored Milk)	**0.15**	**0.00**
log(Price of Organic Milk)	**0.39**	**0.00**	log(Price of PMA)	**0.38**	**0.00**	log(Price of PMA)	0.02	0.84
log(Price of WAC for Low-fat Milk)	-0.02	0.38	log(Price of WAC for Skim Milk)	0.00	0.96	log(Price of WAC for Whole Milk)	**-0.10**	**0.00**
Coupon Value for Low-fat Milk	**0.03**	**0.00**	Coupon Value for Skim Milk	**0.04**	**0.00**	Coupon Value for Whole Milk	**0.04**	**0.00**

Table II-11 Continued

Ice Cream			Natural Cheese			Processed Cheese		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**2.08**	**0.00**	Intercept	**3.98**	**0.00**	Intercept	**3.24**	**0.00**
log(household size)	**0.18**	**0.00**	log(household size)	**0.36**	**0.00**	log(household size)	**0.32**	**0.00**
log(income)	**-0.04**	**0.00**	log(income)	**0.07**	**0.00**	log(income)	**-0.05**	**0.00**
log(age)	**0.38**	**0.00**	log(age)	**-0.07**	**0.00**	log(age)	**0.11**	**0.00**
Education	0.00	0.82	Education	**0.11**	**0.00**	Education	**-0.06**	**0.00**
Middle Atlantic	**-0.06**	**0.03**	Middle Atlantic	**0.06**	**0.00**	Middle Atlantic	0.04	0.12
East North Central	**0.05**	**0.03**	East North Central	**0.06**	**0.01**	East North Central	**0.11**	**0.00**
West North Central	**0.16**	**0.00**	West North Central	0.03	0.15	West North Central	**0.19**	**0.00**
South Atlantic	**0.07**	**0.00**	South Atlantic	0.01	0.48	South Atlantic	**0.13**	**0.00**
East South Central	**0.12**	**0.00**	East South Central	-0.04	0.14	East South Central	**0.18**	**0.00**
West South Central	**0.13**	**0.00**	West South Central	0.00	0.97	West South Central	**0.16**	**0.00**
Mountain	**0.13**	**0.00**	Mountain	**0.15**	**0.00**	Mountain	0.00	0.99
Pacific	**0.19**	**0.00**	Pacific	**0.13**	**0.00**	Pacific	-0.01	0.55
Black/ African American	**-0.13**	**0.00**	Black/ African American	**-0.38**	**0.00**	Black/ African American	**-0.14**	**0.00**
Asian	**-0.09**	**0.00**	Asian	**-0.32**	**0.00**	Asian	**-0.19**	**0.00**
Other	-0.04	0.13	Other	**-0.11**	**0.00**	Other	-0.03	0.22
Hispanic	**-0.06**	**0.01**	Hispanic	**-0.04**	**0.04**	Hispanic	**-0.08**	**0.00**
Presence of Children	**-0.03**	**0.03**	Presence of Children	**-0.04**	**0.00**	Presence of Children	**-0.07**	**0.00**
IMR	**-0.69**	**0.00**	IMR	**-3.05**	**0.00**	IMR	**-1.23**	**0.00**
log(Price of Ice Cream)	**-0.83**	**0.00**	log(Price of Natural Cheese)	**-1.27**	**0.00**	log(Price of Processed Cheese)	**-0.72**	**0.00**
log(Price of Greek Yogurt)	0.04	0.17	log(Price of Processed Cheese)	**0.20**	**0.00**	log(Price of Natural Cheese)	**0.10**	**0.00**
log(Price of non-Greek Yogurt)	-0.01	0.60	log(Price of Conventional Milk)	**0.06**	**0.00**	log(Price of Conventional Milk)	**-0.04**	**0.00**
log(Price of WAC for Ice Cream)	-0.02	0.05	log(Price of WAC for Natural	**0.14**	**0.00**	log(Price of WAC for Processed	-0.02	0.11
Coupon Value for Ice Cream	**0.06**	**0.00**	Coupon Value for Natural Cheese	**0.02**	**0.00**	Coupon Value for Processed Cheese	**0.07**	**0.00**

Table II-11 Continued

Greek Yogurt			non-Greek Yogurt		
	Estimate	p-Value		Estimate	p-Value
Intercept	**2.59**	**0.00**	Intercept	**2.18**	**0.00**
log(household size)	**0.08**	**0.00**	log(household size)	**0.14**	**0.00**
log(income)	**0.17**	**0.00**	log(income)	**0.03**	**0.00**
log(age)	-0.04	0.32	log(age)	**0.08**	**0.01**
Education	**0.13**	**0.00**	Education	**0.06**	**0.00**
Middle Atlantic	**-0.12**	**0.00**	Middle Atlantic	-0.02	0.53
East North Central	**-0.25**	**0.00**	East North Central	-0.05	0.08
West North Central	**-0.17**	**0.00**	West North Central	-0.02	0.49
South Atlantic	**-0.26**	**0.00**	South Atlantic	**-0.10**	**0.00**
East South Central	**-0.46**	**0.00**	East South Central	**-0.21**	**0.00**
West South Central	**-0.32**	**0.00**	West South Central	**-0.15**	**0.00**
Mountain	**-0.26**	**0.00**	Mountain	-0.02	0.47
Pacific	**-0.23**	**0.00**	Pacific	0.00	0.93
Black/ African American	**-0.30**	**0.00**	Black/ African American	**-0.16**	**0.00**
Asian	**-0.24**	**0.00**	Asian	**-0.07**	**0.04**
Other	-0.06	0.12	Other	-0.02	0.60
Hispanic	**-0.04**	**0.20**	Hispanic	0.00	0.93
Presence of Children	-0.01	0.62	Presence of Children	**0.18**	**0.00**
IMR	**-0.35**	**0.00**	IMR	**-0.89**	**0.00**
log(Price of Greek Yogurt)	**-1.29**	**0.00**	log(Price of non-Greek Yogurt)	**-1.00**	**0.00**
log(Price of non-Greek Yogurt)	**0.34**	**0.00**	log(Price of Greek Yogurt)	**-0.17**	**0.00**
log(Price of Ice Cream)	**0.12**	**0.00**	log(Price of Ice Cream)	0.00	0.72
log(Price of Conventional Milk)	**0.21**	**0.00**	log(Price of Conventional Milk)	**0.04**	**0.03**
log(Price of WAC for Greek Yogurt)	**0.06**	**0.00**	log(Price of WAC for non-Greek Yogurt)	0.02	0.25
Coupon Value for Greek Yogurt	**0.07**	**0.00**	Coupon Value for non-Greek Yogurt	**0.06**	**0.00**

Table II-11 Continued

Butter			Margarine		
	Estimate	p-Value		Estimate	p-Value
Intercept	**2.41**	**0.00**	Intercept	**2.09**	**0.00**
log(household size)	**0.39**	**0.00**	log(household size)	**0.45**	**0.00**
log(income)	**-0.03**	**0.00**	log(income)	**-0.09**	**0.00**
log(age)	**0.37**	**0.00**	log(age)	**0.53**	**0.00**
Education	**-0.08**	**0.00**	Education	**-0.07**	**0.00**
Middle Atlantic	-0.02	0.43	Middle Atlantic	**-0.11**	**0.00**
East North Central	-0.02	0.42	East North Central	**-0.19**	**0.00**
West North Central	0.03	0.22	West North Central	**-0.14**	**0.00**
South Atlantic	**-0.10**	**0.00**	South Atlantic	**-0.18**	**0.00**
East South Central	**-0.11**	**0.00**	East South Central	**-0.15**	**0.00**
West South Central	**-0.08**	**0.00**	West South Central	**-0.19**	**0.00**
Mountain	0.00	0.89	Mountain	**-0.15**	**0.00**
Pacific	-0.02	0.34	Pacific	**-0.14**	**0.00**
Black/ African American	**-0.17**	**0.00**	Black/ African American	**-0.14**	**0.00**
Asian	**-0.27**	**0.00**	Asian	**-0.30**	**0.00**
Other	0.00	0.89	Other	-0.02	0.36
Hispanic	**-0.16**	**0.00**	Hispanic	**-0.11**	**0.00**
Presence of Children	**-0.10**	**0.00**	Presence of Children	**-0.14**	**0.00**
IMR	**-0.63**	**0.00**	IMR	**-0.47**	**0.00**
log(Price of Butter)	**-0.64**	**0.00**	log(Price of Margarine)	**-0.71**	**0.00**
log(Price of Margarine)	**-0.06**	**0.00**	log(Price of Butter)	**0.14**	**0.00**
log(Price of WAC for Butter)	**0.03**	**0.01**	log(Price of WAC for Margarine)	**-0.02**	**0.03**
Coupon Value for Butter	**0.05**	**0.00**	Coupon Value for Margarine	**0.07**	**0.00**

Table II-12 F- tests for Region and Race, and Adjusted R^2 of the Demand Functions for the Respective Dairy Products

	F-test for region		F-test for race		Adjusted R^2
	F- Statistic	P-value	F- Statistic	P-value	
Plant-based Milk Alternatives	**5.35**	**0.00**	**2.72**	**0.04**	0.19
Flavored Milk	**2.51**	**0.01**	**13.55**	**0.00**	0.28
Organic Milk	1.76	0.08	**3.28**	**0.02**	0.10
Low-fat Milk	**3.78**	**0.00**	**54.91**	**0.00**	0.28
Skim Milk	**18.72**	**0.00**	**25.95**	**0.00**	0.29
Whole Milk	**4.03**	**0.00**	**24.51**	**0.00**	0.32
Butter	**10.08**	**0.00**	**45.85**	**0.00**	0.14
Margarine	**9.33**	**0.00**	**45.35**	**0.00**	0.23
Ice Cream	**26.62**	**0.00**	**22.96**	**0.00**	0.26
Natural Cheese	**20.28**	**0.00**	**274.08**	**0.00**	0.32
Processed Cheese	**29.39**	**0.00**	**38.10**	**0.00**	0.17
Greek Yogurt	**20.50**	**0.00**	**51.42**	**0.00**	0.17
Non-Greek Yogurt	**12.35**	**0.00**	**23.49**	**0.00**	0.19

Table II-13 Marginal Effects and Elasticities Associated with the Demand Model

Plant-based Milk Alternatives		Flavored Milk		Organic Milk	
Elasticity		***Elasticity***		***Elasticity***	
log(household size)	0.16	log(household size)	0.28	log(household size)	0.16
log(income)	0.03	log(income)	0.03	log(income)	0.19
log(age)	-0.04	log(age)	0.16	log(age)	-0.11
log(Price of PMA)	-1.18	log(Price of Flavored Milk)	-1.30	log(Price of Organic Milk)	-1.00
log(Price of Conventional Milk)	0.45	log(Price of PMA)	0.37	log(Price of Flavored Milk)	0.43
log(Price of Organic Milk)	0.20	log(Price of Conventional Milk)	0.44	log(Price of Conventional Milk)	0.22
log(Price of Flavored Milk)	0.09	log(Price of Organic Milk)	0.16	log(Price of PMA)	0.16
log(Price of WAC for PMA)	0.29	log(Price of WAC for Flavored Milk)	-0.10	log(Price of WAC for Organic Milk)	0.46
Coupon Value for PMA	0.09	Coupon Value for Flavored Milk	0.06	Coupon Value for Organic Milk	0.05
Marginal Effect		***Marginal Effect***		***Marginal Effect***	
Education	0.12	Education	-0.03	Education	0.16
Middle Atlantic	-0.10	Middle Atlantic	0.00	Middle Atlantic	0.12
East North Central	-0.21	East North Central	0.18	East North Central	0.01
West North Central	-0.15	West North Central	0.19	West North Central	0.06
South Atlantic	-0.17	South Atlantic	-0.01	South Atlantic	0.10
East South Central	-0.17	East South Central	0.09	East South Central	0.14
West South Central	-0.20	West South Central	0.14	West South Central	0.09
Mountain	0.10	Mountain	0.16	Mountain	0.10
Pacific	0.06	Pacific	-0.12	Pacific	0.04
Black/ African American	0.10	Black/ African American	-0.33	Black/ African American	-0.32
Asian	0.13	Asian	-0.11	Asian	0.26
Other	0.15	Other	-0.13	Other	0.01
Hispanic	0.14	Hispanic	-0.08	Hispanic	0.04
Presence of Children	-0.05	Presence of Children	0.03	Presence of Children	0.36
IMR	-0.23	IMR	-0.30	IMR	-0.34

Table II-13 Continued

Low-fat Milk		Skim Milk		Whole Milk	
Elasticity		***Elasticity***		***Elasticity***	
log(household size)	1.19	log(household size)	0.37	log(household size)	0.67
log(income)	0.003	log(income)	0.28	log(income)	-0.28
log(age)	0.42	log(age)	0.47	log(age)	-0.18
log(Price of Low-fat Milk)	-1.45	log(Price of Skim Milk)	-1.63	log(Price of Whole Milk)	-1.97
log(Price of Whole Milk)	0.24	log(Price of Organic Milk)	-0.30	log(Price of Organic Milk)	0.32
log(Price of Skim Milk)	0.77	log(Price of Low-fat Milk)	0.10	log(Price of Low-fat Milk)	0.41
log(Price of Flavored Milk)	-0.23	log(Price of Whole Milk)	0.68	log(Price of Skim Milk)	0.51
log(Price of PMA)	0.13	log(Price of Flavored Milk)	-0.02	log(Price of Flavored Milk)	0.27
log(Price of Organic Milk)	0.04	log(Price of PMA)	0.18	log(Price of PMA)	0.09
log(Price of WAC for Low-fat Milk)	-0.61	log(Price of WAC for Skim Milk)	-0.26	log(Price of WAC for Whole Milk)	-0.12
Coupon Value for Low-fat Milk	0.03	Coupon Value for Skim Milk	0.04	Coupon Value for Whole Milk	0.04
Marginal Effect		***Marginal Effect***		***Marginal Effect***	
Education	-0.12	Education	0.26	Education	-0.32
Middle Atlantic	-0.24	Middle Atlantic	0.45	Middle Atlantic	-0.12
East North Central	-0.06	East North Central	0.32	East North Central	-0.25
West North Central	-0.08	West North Central	0.89	West North Central	-0.20
South Atlantic	-0.29	South Atlantic	0.28	South Atlantic	0.04
East South Central	-0.06	East South Central	0.33	East South Central	0.17
West South Central	-0.25	West South Central	0.05	West South Central	0.15
Mountain	-0.03	Mountain	-0.23	Mountain	-0.07
Pacific	-0.25	Pacific	-0.31	Pacific	-0.13
Black/ African American	-0.81	Black/ African American	-1.25	Black/ African American	0.05
Asian	-0.76	Asian	-0.57	Asian	0.00
Other	-0.28	Other	-0.39	Other	0.06
Hispanic	0.02	Hispanic	-0.04	Hispanic	0.04
Presence of Children	0.09	Presence of Children	-0.08	Presence of Children	0.03
IMR	-1.30	IMR	-0.52	IMR	-0.74

Table II-13 Continued

Ice Cream		Natural Cheese		Processed Cheese	
Elasticity		***Elasticity***		***Elasticity***	
log(household size)	0.48	log(household size)	0.82	log(household size)	0.73
log(income)	-0.09	log(income)	0.11	log(income)	-0.06
log(age)	0.51	log(age)	-0.23	log(age)	0.18
log(Price of Ice Cream)	-0.83	log(Price of Natural Cheese)	-1.28	log(Price of Processed Cheese)	-0.68
log(Price of Greek Yogurt)	0.08	log(Price of Processed Cheese)	0.20	log(Price of Natural Cheese)	0.08
log(Price of non-Greek Yogurt)	-0.07	log(Price of Conventional Milk)	-0.004	log(Price of Conventional Milk)	-0.13
log(Price of WAC for Ice Cream)	-0.13	log(Price of WAC for Natural Cheese)	0.29	log(Price of WAC for Processed Cheese)	-0.04
Coupon Value for Ice Cream	0.06	Coupon Value for Natural Cheese	0.02	Coupon Value for Processed Cheese	0.07
Marginal Effect		***Marginal Effect***		***Marginal Effect***	
Education	-0.05	Education	0.11	Education	-0.16
Middle Atlantic	-0.13	Middle Atlantic	0.00	Middle Atlantic	0.02
East North Central	0.13	East North Central	0.11	East North Central	0.20
West North Central	0.23	West North Central	0.07	West North Central	0.34
South Atlantic	0.13	South Atlantic	0.03	South Atlantic	0.19
East South Central	0.26	East South Central	-0.04	East South Central	0.38
West South Central	0.28	West South Central	-0.02	West South Central	0.24
Mountain	0.20	Mountain	0.23	Mountain	-0.02
Pacific	0.19	Pacific	0.13	Pacific	-0.14
Black/ African American	-0.23	Black/ African American	-0.62	Black/ African American	-0.37
Asian	-0.33	Asian	-0.93	Asian	-0.54
Other	-0.08	Other	-0.16	Other	-0.12
Hispanic	-0.13	Hispanic	-0.07	Hispanic	-0.14
Presence of Children	-0.06	Presence of Children	-0.11	Presence of Children	-0.14
IMR	-0.69	IMR	-2.89	IMR	-1.23

Table II-13 Continued

Greek Yogurt		non-Greek Yogurt	
Elasticity		***Elasticity***	
log(household size)	0.18	log(household size)	0.46
log(income)	0.25	log(income)	0.05
log(age)	-0.14	log(age)	-0.14
log(Price of Greek Yogurt)	-1.54	log(Price of non-Greek Yogurt)	-1.11
log(Price of non-Greek Yogurt)	0.64	log(Price of Greek Yogurt)	-0.23
log(Price of Ice Cream)	0.24	log(Price of Ice Cream)	-0.03
log(Price of Conventional Milk)	0.29	log(Price of Conventional Milk)	-0.04
log(Price of WAC for Greek Yogurt)	0.04	log(Price of WAC for non-Greek Yogurt)	-0.04
Coupon Value for Greek Yogurt	0.07	Coupon Value for non-Greek Yogurt	0.06
Marginal Effect		***Marginal Effect***	
Education	0.22	Education	0.14
Middle Atlantic	-0.16	Middle Atlantic	-0.07
East North Central	-0.30	East North Central	-0.06
West North Central	-0.20	West North Central	-0.01
South Atlantic	-0.33	South Atlantic	-0.15
East South Central	-0.57	East South Central	-0.32
West South Central	-0.40	West South Central	-0.18
Mountain	-0.25	Mountain	-0.04
Pacific	-0.27	Pacific	-0.01
Black/ African American	-0.43	Black/ African American	-0.30
Asian	-0.35	Asian	-0.19
Other	-0.09	Other	-0.08
Hispanic	-0.03	Hispanic	0.06
Presence of Children	-0.01	Presence of Children	0.43
IMR	-0.35	IMR	-0.89

Table II-13 Continued

Butter		Margarine	
Elasticity		***Elasticity***	
log(household size)	0.61	log(household size)	0.70
log(income)	0.07	log(income)	-0.20
log(age)	0.69	log(age)	0.64
log(Price of Butter)	-0.61	log(Price of Margarine)	-0.77
log(Price of Margarine)	0.15	log(Price of Butter)	0.05
log(Price of WAC for Butter)	0.14	log(Price of WAC for Margarine)	-0.22
Coupon Value for Butter	0.05	Coupon Value for Margarine	0.07
Marginal Effect		***Marginal Effect***	
Education	0.04	Education	-0.23
Middle Atlantic	-0.03	Middle Atlantic	-0.16
East North Central	-0.05	East North Central	-0.13
West North Central	0.04	West North Central	-0.07
South Atlantic	-0.20	South Atlantic	-0.11
East South Central	-0.28	East South Central	0.05
West South Central	-0.20	West South Central	-0.07
Mountain	0.00	Mountain	-0.25
Pacific	-0.08	Pacific	-0.25
Black/ African American	-0.37	Black/ African American	0.01
Asian	-0.50	Asian	-0.54
Other	-0.10	Other	-0.02
Hispanic	-0.28	Hispanic	-0.06
Presence of Children	-0.13	Presence of Children	-0.22
IMR	-0.63	IMR	-0.47

Table II-14 Comparison of Models, Data, Dairy Products, Uncompensated Own-Price Elasticity and Income/Expenditure Elasticity with Other Studies in the Extant Literature

Study	Model	Data	Dairy products	Own price elasticity	Income elasticity
Our study	Heckman two step procedure; Single equation demand model	Cross-sectional data, 2015 Nielsen Homescan data	Flavored Milk	-1.30	0.03
			Organic Milk	-1.00	0.19
			Skim Milk	-1.63	0.28
			Whole Milk	-1.97	-0.28
			Low-fat Milk	-1.45	0.003
			Plant-based Milk Alternatives	-1.18	0.03
			Butter	-0.61	0.07
			Margarine	-0.77	-0.20
			Ice Cream	-0.83	-0.09
			Natural Cheese	-1.28	0.11
			Processed Cheese	-0.68	-0.06
			Non-Greek Yogurt	-1.11	0.05
			Greek Yogurt	-1.54	0.25
Robinson (2017)	Seemingly unrelated regression	Time series data, weekly Nielsen Homescan data from	Chobani Yogurt	-2.64	2.89
			Dannon Yogurt	-1.43	2.34
			Yoplait Yogurt	-0.37	1.98
			Stonyfield Yogurt	-0.86	1.64
			Private Label Yogurt	-0.19	0.38

Table II-14 Continued

Study	Model	Data	Dairy products	Own price elasticity	Expenditure elasticity
Heien and Wessells (1988)	Two-stage budgeting procedure; AIDS model	Cross-sectional data, Household Food Consumption Survey from 1977 to 1978	Milk	-0.63	0.77
			Cheese	-0.52	1.01
			Cottage Cheese	-1.1	1.02
			Butter	-0.73	1.06
			Margarine	-0.25	0.84
Maynard and Liu (1999)	A double-log model/ A linearized AIDS model[b]/ NBR[c]	Time series data, weekly Nielsen Homescan data from 1996-1998	White Milk	-0.54 (-0.63[b], -0.78[c])	Not Provided
			Flavored Milk	-1.41 (-1.40[b], -1.47[c])	
			Chunk Cheese	-2.18 (-1.96[b], -3.03[c])	
			Sliced Cheese	-1.64 (-1.72[b], -2.08[c])	
			Snack Cheese	-0.58 (-1.68[b], -0.99[c])	
			Shredded Cheese	-1.35 (-1.70[b], -2.66[c])	
			Butter	-0.63 (-0.19[b], -2.33[c])	
			Ice Cream	-0.88 (-0.65[b], -1.65[c])	
			Frozen Yogurt	-1.31 (-1.49[b], -1.64[c])	
			Frozen Novelties	-2.99 (-3.39[b], -3.18[c])	

Note: [a] Own-price elasticity obtained from SUR model. [b] Own-price elasticity obtained from AIDS model .[c] Own-price elasticity obtained from NBR model.

Table II-14 Continued

Study	Model	Data	Dairy products	Own price elasticity	Expenditure elasticity
Yen, S. T. et al. (2002)	A censored translog demand system	Cross-sectional data, the 1987-1988 US Nationalwide Food Consumption Survey	Butter	-1.13	1.00
			Margarine	-0.99	1.00
Davis, C. G. et al.(2009)	A censored translog demand system	Cross-sectional data, 2005 Nielsen Homescan retail data	Bulk Ice Cream	-1.00	1.01
			Ice Milk	-1.28	0.84
			Ice Cream Novelty	-1.96	0.50
Davis, C. G. et al.(2010)	A censored AIDS model	Cross-sectional data, 2007 Nielsen Homescan data	Bulk Ice Cream	-0.91	1.01
			Sherbet	-1.21	0.93
			Refrigerated Yogurt	-1.19	1.00
			Frozen Yogurt	-1.26	1.00
			Drinkable Yogurt	-1.73	0.96
			Whole Milk	-1.70	0.77
			Reduced Fat Milk	-1.57	1.14
			Canned Milk	-1.32	1.06
			Natural Cheese	-1.73	1.04
			Processed Cheese	-0.99	0.85
			Cottage Cheese	-1.68	1.10
			Butter	-1.87	0.97
			Margarine	-0.95	0.94

Table II-14 Continued

Study	Model	Data	Dairy products	Own price elasticity	Expenditure elasticity
Davis, C. G. et al.(2011)	A censored AIDS model	Cross-sectional data, 2006 Nielsen Homescan retail data	Natural Cheese	-1.84	1.05
			Cottage Cheese	-2.59	1.13
			Processed Cheese	-1.63	0.94
			Grated Cheese	-2.25	1.02
			Shredded Cheese	-3.77	0.82
			Other Cheese	-1.55	0.98
Davis, C.G. *et al.* (2012)	A censored AIDS model	Cross-sectional data, 2007 Nielsen Homescan retail data	Whole Milk	-1.48	0.96
			1% Milk	-1.40	0.99
			2% Milk	-1.39	1.02
			Skim Milk	-3.24	1.01
			Whole Flavored Milk	-2.52	1.23
			1% Flavored Milk	-2.39	1.19
			2% Flavored Milk	-3.82	1.23
			Skim Flavored Milk	-1.94	1.37
			Other Milk	-1.07	1.00

CHAPTER III

DEMAND SYSTEM MODELS OF DAIRY PRODUCTS AND DAIRY ALTERNATIVE PRODUCTS

Introduction

Background

Dairy products play an important role in the American diet. Dairy foods contain vital nutrients for the health and maintenance of the human body. The notable nutrients include calcium, vitamin D, protein, and potassium. Especially, dairy products are the primary source of calcium in the American diet, considered to be important for bone health (ChooseMyPlate.gov, Dec 14, 2018). ChooseMyPlate of the United States Department of Agriculture (USDA) suggests that diets containing 3 cups of dairy products per day can improve bone mass. The major dairy products consumed in the United States include fluid milk, cheese, butter, yogurt, and ice cream. In the U.S. dairy market, the per capita consumption of fluid milk has been declining for decades, while per capita consumption of cheese (including both natural cheese and processed cheese) has been on an increasing upward trend. Per capita consumption of butter and yogurt (both Greek yogurt and non-Greek yogurt) also have increased sharply since the year of 2000. The per capita consumption of low-fat ice cream is quite stable over the last two decades, but regular ice cream has shown a slowly declining trend since 2000. These quarterly/annual per capita consumption trends of different dairy products are shown in Figure 1- 6, based on the USDA and Statista data.

On the other hand, more dairy alternative products have been offered to U.S. consumers in the past ten years. In particular, plant-based milk alternatives (e.g. almond milk, coconut milk, and so on) have gained popularity (Dharmasena and Capps, 2014). Table III-1 shows the market penetration for different dairy products from 2007 to 2015[11]. The market penetration of plant-based milk alternatives has increased by 160% from 11% to 29%. Greek yogurt is another dairy product with an increasing presence (Dharmasena, Okrent, and Capps, 2014). The market penetration of Greek yogurt has increased to 54% in 2015 since its first appearance in 2007. It is important to re-consider demand interrelationships among different dairy products as well as dairy alternative products.

Objectives

The general objective of this study is to estimate the demand for dairy products and dairy alternative products at the aggregated household level based on monthly time-series data for calendar years 2010[12] to 2015.

The specific objectives are as follows:

(1) To examine the aggregated demand for nine dairy products and dairy alternative products in the United States based on the Quadratic Almost Ideal Demand System (QUAIDS) and Barten's synthetic model;

(2) To estimate uncompensated and compensated price elasticities as well as

[11] The market penetration is calculated based on the Nielsen Homescan panel data for calendar years 2007 to 2015. The dataset for calendar year 2015 is the most recent data set available for analysis in the Agribusiness, Food, and Consumer Economics Research Center in the Department of Agricultural Economics at Texas A&M University.

[12] Calendar year 2010 is selected as the start of the time-series data set because the market shares for Greek yogurt are relative small (<1%) compared to other dairy categories before 2010, which might lead to implausible estimation results.

expenditure elasticities for nine dairy categories; and

(3) To analyze the interrelationships among the nine dairy products based on the compensated cross-price elasticities estimated from the QUAIDS model and the Barten model.

The most recent demand system analysis associated with different dairy categories was done in 2010 (Davis, Dong, Blayney, and Owens, 2010). Our study provides a more up-to-date analysis of the demand for dairy products as well as dairy alternative products, which is currently lacking in extant literature.

Literature Review

Many studies concerning the demand for dairy products have been conducted in the extant literature. Most of the previous studies focus on one or two individual dairy products, notably milk and cheese. In these works of literature, Almost Ideal Demand System (AIDS) is the most popular method to conduct the demand analysis. At the same time, cross-sectional data sets are usually used to obtain the price and expenditure elasticities. These elasticities display notable variations in different literature.

Heien and Wessells (1988) estimated an AIDS model with 12 food items based on the Household Food Consumption Survey, a cross-sectional data set over the period 1977 to 1978. Own-price elasticities for milk (-0.63), butter (-0.73), and cheese (-0.52) were found to be in the inelastic range. Cottage cheese (-1.10) was in the elastic range. The expenditure elasticity estimates indicated that milk was a necessity and cheese, cottage cheese, and butter were luxuries.

Maynard and Liu (1999) estimated the demand for dairy products including white milk, flavored milk, chunk cheese, sliced cheese, snack cheese, shredded cheese, butter, frozen yogurt, ice cream, and novelties using a double-log model, a linearized AIDS model, and the Barten's Synthetic model based on weekly Nielsen Homescan retail data at the aggregated household level for the years 1996 through 1998. From their study, NBR nested in the Barten's Synthetic model best described the data. Most of the own-price elasticities estimated from all three models were found to be in the elastic range, different from previous studies. More elastic own-price elasticities on chunk cheese (-3.03), sliced cheese (-2.08), and shredded cheese (-2.66) were obtained from the NBR model compared to the other two models, while the own-price elasticities for other dairy product were similar across three models.

Davis et al. (2010) estimated the demands for twelve dairy products and margarine using a censored AIDS model and Nielsen 2007 Homescan data. Ten of the twelve uncompensated and compensated own-price elasticities were statistically significant. The compensated and uncompensated own-price elasticities were estimated to be -0.77 and -0.91 for bulk ice cream, -1.21 and -1.21 for sherbet/ice milk, -1.08 and -1.19 for refrigerated yogurt, -1.26 and -1.26 for frozen yogurt, -1.72 and -1.73 for drinkable yogurt, -1.65 and -1.70 for whole milk, -1.26 and -1.57 for reduced-fat milk, -1.31 and -1.32 for canned milk, -1.61 and -1.73 for natural cheese, -0.89 and -0.99 for processed cheese, -1.64 and -1.68 for cottage cheese, -1.81 and -1.87 for butter, -0.90 and -0.95 for margarine. Strong substitution relationships among ice cream, reduced-fat milk, and natural cheese were evident. Whole milk and processed cheese were found to be necessities, while the expenditure elasticities for the other dairy products were found to be luxuries.

Davis *et al.* (2011) identified price and socio-demographic factors that affect the demand for cheese using a censored AIDS model based on Nielsen Homescan retail data for the calendar year 2006. The compensated and uncompensated own-price elasticities were estimated to be -1.54 and -1.84 for natural cheese, and -1.32 and -1.63 for processed cheese. Expenditure elasticities indicated that natural cheese was a luxury and processed cheese was a necessity.

Model

Two demand system models: the Quadratic Almost Ideal Demand System (QUAIDS) and the Barten's Synthetic Model are used in this research to analyze the interrelationship among the nine dairy products and dairy alternative products. Unlike the AIDS model widely used in previous studies which only allows for a linear Engel curve in the logarithm of total expenditure, the QUAIDS model allows a quadratic Engel curve, which permits goods to be luxuries at some income level and necessities at others. At the same time, the Barten's Synthetic Model nests four widely used demand systems: the Rotterdam model, the Almost Ideal Demand System (AIDS), the Central Bureau of Statistic (CBS) model, and the National Bureau of Research (NBR) model.

QUAIDS (Quadratic Almost Ideal Demand System)

The QUAIDS model is first introduced by Deaton and Muellbauer (1980) and Banks, Blundell, and Lewbel (1997). The specification of this model is as follows:

$$w_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \log(p_j) + \beta_i \log\left(\frac{m}{a(p)}\right) + \frac{\lambda_i}{b(p)} \log\left(\frac{m}{a(p)}\right)^2 \qquad (1)$$

where

w_i is the expenditure share on good i,

p_i is the price for good i,

m is the total expenditure,

the price index $a(p)$ is specified as

$$a(p) = \alpha_0 + \sum_{i=1}^{n} \alpha_i \log(p_i) + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij} \log(p_i) \log(p_j), \quad (2)$$

and the price aggregator $b(p)$ is specified as

$$b(p) = \prod_{i=1}^{n} p_i^{\beta_i} \quad (3)$$

The following theoretical constraints should be imported during estimation:

1) $\sum_{i=1}^{n} \alpha_i = 1; \sum_{i=1}^{n} \beta_i = 0; \sum_{i=1}^{n} \gamma_{ij} = 0;$ Adding-up condition,

2) $\sum_{j=1}^{n} \gamma_{ij} = 0;\ \sum_{i=1}^{n} \lambda_i = 0;$ Homogeneity condition,

3) $\gamma_{ij} = \gamma_{ji}$ Symmetry of the Slutsky matrix.

The income and price elasticities can be calculated as below:

1) income elasticity: $\eta_i = \frac{\mu_i}{w_i} + 1$ (4)

2) uncompensated elasticity: $\varepsilon_{ij}^{u} = \frac{\mu_{ij}}{wi} - \delta_{ij}$ (5)

3) compensated elasticity[13]: $\varepsilon_{ij}^{c} = \varepsilon_{ij}^{u} + \eta_i w_j$

(6)

where

$$\mu_i = \frac{\partial w_i}{\partial \log(m)} = \beta_i + \frac{2\lambda_i}{b(p)} \log\left(\frac{m}{a(p)}\right) \quad (7)$$

$$\mu_{ij} = \frac{\partial w_i}{\partial \log(p_j)} = r_{ij} - \mu_i\left(a_j + \sum_{k=1}^{n} \gamma_{jk} \log(p_k)\right) - \frac{\lambda_i \beta_j}{b(p)}\left\{\log\left(\frac{m}{b(p)}\right)\right\}^2 \quad (8)$$

$\delta_{ij} = \begin{cases} 1, & when\ i = j \\ 0, & when\ i \neq j \end{cases}$ is the Kronecker delta.

[13] Derived from Slutsky's equation.

Barten's Synthetic Model

Barten's synthetic model is first developed by Barten (1993). The Barten model is specified as follows (Matsuda, 2005):

$$w_i d \ln q_i = (a_i + \lambda w_i) d \log Q + \sum_j \left[b_{ij} - \mu w_i \left(\delta_{ij} - w_j\right)\right] d \log p_j \,, i = 1, \ldots, n, \quad (9)$$

where

w_i is the budget share on good i,

p_i is the price for good i,

q_i is the quantity for good i,

$d \log q_i$ is the logarithmic differential of Marshallian demand for good i.

In practice, $d \log q_i \approx \Delta \log q_i = \log q_{i,t} - \log q_{i,t-1}$,

$d \log Q \equiv \sum_i w_i \, d \ln q_i$ denotes the Divisia volume index,

$\delta_{ij} = \{ \begin{matrix} 1, & when\ i = j \\ 0, & when\ i \neq j \end{matrix}$ is the Kronecker delta.

The following constraints should be obeyed:

1) Adding up: $\sum_{i=1}^{n} b_{ij} = 0$; $\sum_{i=1}^{n} a_i = 1 - \lambda$.

2) $\sum_{j=1}^{n} b_{ij} = 0$ for homogeneity.

3) Symmetry: $b_{ij} = b_{ji}$.

Parameters can be restricted such that:

1) $\lambda = 0,\ \mu = 0$ Rotterdam model.

2) $\lambda = 1,\ \mu = 1$ AIDS model.

3) $\lambda = 1,\ \mu = 0$ CBS model.

4) $\lambda = 0,\ \mu = 1$ NBR model.

The elasticities are given as below:

The uncompensated elasticity of good j with respect to the price of good i is:

$$\varepsilon_{ij}^{u} = -\left(\frac{a_i+\lambda w_i}{w_i}\right) w_j + \frac{b_{ij}-\mu w_i(\delta_{ij}-w_j)}{w_i} \tag{10}$$

The elasticity of good i with respect to the income is:

$$\eta_i = \frac{a_i+\lambda w_i}{w_i} \tag{11}$$

The compensated elasticity of good j with respect to the price of good i is:

$$\varepsilon_{ij}^{c} = \varepsilon_{ij}^{u} + \eta_i w_j \tag{12}$$

Data

Data used in this study are monthly observations of dairy products and dairy alternative products from Nielsen Homescan Panel. The period of the data is from January 2010 to November 2015[14], and purchasing records are aggregated over households. The dairy products and dairy alternative products are separated into nine categories, which are: (1) flavored milk (mainly chocolate milk), (2) white milk (contains both organic and conventional white milk), (3) non-Greek yogurt, (4) Greek yogurt, (5) butter, (6) natural cheese, (7) processed cheese, (8) plant-based milk alternatives[15], and (9) ice cream.

In the Nielsen Homescan Panel, the purchasing records are reported for each household over time, including the total amount paid in dollars, the coupon value in dollars, and the quantity purchased in ounces. First, all of the purchasing records are aggregated over households for the same month, thus a total of 71 observations are used for further analysis, which includes the aggregated total amount paid per month, the aggregated coupon value per month, and the aggregated quantity per month for each of the aforementioned airy categories. Second, the aggregated coupon values per month are subtracted from the aggregated total amount paid per month to derive the aggregated monthly expenditure for each dairy category. Next, the monthly expenditure and quantity

[14] The Nielsen Homescan Panel available for this study does not contain purchasing records for the entire month of December 2015. Thus, November 2015 is set as the end of the monthly time-series data.
[15] Products of two brands- Blue Diamond and Silk are used to represent plant-based milk alternatives, since these two brands have the largest market shares by far in this category over calendar years 2010 to 2015.

records are divided by the total number of households in the Nielsen Panel of the calendar year; thus per household-based expenditure and quantity data are calculated. The reason for applying this step is that the number of households who purchased dairy products not only differs over the nine respective categories but also over the monthly time periods. Subsequently, the expenditure and quantity data are expressed in terms of dollars and ounces purchased per household per month. Then, the monthly unit values for each dairy category are calculated by dividing the monthly expenditure by monthly quantity. Next, all the expenditures of dairy categories per month are summed to derive the total monthly expenditure. We divide monthly expenditure for each dairy category by total monthly expenditure to obtain the respective budget shares for each dairy category per month. In the end, the data set for this analysis includes monthly quantity per household (ounces), unit values ($/ounce), monthly expenditures per household ($), and monthly budget shares from January 2010 to November 2015 (71 observations).

Table III-2 shows the descriptive statistics of quantities (ounces), total expenditures ($), budget shares, unit values ($/ounce), CPI, and Income ($) for nine dairy categories respectively. First, white milk is the most purchased dairy product per household per month on average at 213.80 ounces, followed by ice cream at 23.71 ounces, natural cheese at 23.64 ounces, and non-Greek yogurt at 22.54 ounce. Monthly purchases of processed cheese per household (9.43 ounces) are over two times less than monthly purchases of natural cheese on average. Monthly purchases of Greek yogurt per household (6.15 ounces) are nearly four times less than monthly purchases of non-Greek yogurt on average. The monthly purchases of flavored milk, plant-based milk alternatives, and butter per household are 7.89, 8.28, and 7.26 ounces on average. Second, the budget shares on average in descending order are as follows: natural cheese 30%, white milk 28%, non-Greek yogurt 11%, processed cheese 10%, ice cream 7%, butter 7%, Greek yogurt 5%, plant-based milk alternatives 2%, and flavored milk 1%. Third, the unit values on average over the period in descending order are as follows: natural cheese 26 cents/ounce, processed cheese 21 cents/ounce, butter 19 cents/ounce, Greek yogurt 18 cents/ounce, non-Greek yogurt 10 cents/ounce, ice cream 6 cents/ounce, plant-based milk alternatives 5 cents/ounce, flavored milk 4 cents/ounce, and white milk 3 cents/ounce. The average price of margarine is over two times less than the average price of butter at 9 cents/ounce. Last, the monthly total expenditures on the nine dairy products per household are $20.46 on average over the period 2010 to 2015. The income per capita over this period is $39,618 on average.

Estimation

Various issues are addressed during the estimation of the demand system models: (1) autocorrelation; (2) endogeneity; and (3) Seasonality

Autocorrelation

Because time-series data are used in this research, the presence of serial correlation should be considered by examining the autocorrelation function (ACF) and the partial autocorrelation functions (PACF) of the disturbance terms. The model associated with autocorrelation is specified as follows:

$$y_{it} = f(\,x_{it}, \beta) + \sum \rho_k (y_{it-k} - f(x_{it-k}, \beta)) + \sum_{s=1}^{11} \theta_s D_s + \epsilon_{it} \qquad (13)$$

where k is the number of lag terms, y_{it} is the budget share for QUAIDS and the budget share times the logarithm of differential of Marshallian demand for Bartem model, $f(\,x_{it}, \beta)$ is the function form from equation (1) for QUAIDS and the function form from equation (9) for Barten model. A close study of ACF and PACF plot indicates the presence of a first-order autoregression process of disturbance terms (AR(1)) in QUAIDS, and no autocorrelation for Barten model.

Endogeneity

In this demand system analysis, we assume the unit values as proxies for price are exogenous[16]. The quantities and expenditures are endogenous; since total expenditure is

[16] Prices also may be endogenous as unit values are derived as the ratio of expenditure to quantities. We tried to use instrumental variables to deal with the endogeneity problem, and the associated reduced form is as follows: $\ln p_t = f\ (c, \ln CPI_t\,, lags\ of \ln p)$, where $\ln p_t$ is the logarithm of price at period t, $\ln CPI_t$

defined as the sum of expenditures of each dairy category, It is reasonable to treat the total expenditure as endogenous (Dharmasena and Capps, 2012). Following Dhar, Chavas, and Gould (2003) and Lakkakula, Schmitz, and Ripplinger (2016), we specify the reduced form equations for the total expenditure to deal with the endogeneity problem as follows:

$$\ln m_t = f\ (c, \ln DPI_t\ , lags\ of \ln m) \quad (14)$$

where $\ln m_t$ is the logarithm of total expenditure at period t, c is a constant, $\ln DPI_t$ is the logarithm of disposable income at period t, and $lags\ of \ln m$ is the lags of the logarithm of total expenditure. The instrument variables used in this equation are similar to those used in the works of Attfield (1985), Capps et al. (1994), and Dharmasena and Capps (2012). In order to select the optimal lags of $\ln m$ as the instrumental variables, we considered criteria such as AIC (Akaike Information Criterion), BIC (Bayesian Information Criterion), adjusted R^2, and Root Mean Square Error (RMSE). Two month model and three month lags models have similar values associated with these criteria. Based on the principle of parsimony, a lag of order 2 for $\ln m$ is used in the instrumental regression. As well, the ACF and PACF indicate that second-order of autocorrelation is evident for the equation (14). The estimation results from the reduced form equation are shown in Table III-3.

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is the logarithm of Consumer Price Index at period t, and $lags\ of \ln p$ is the lags of the logarithm of price. Instrumental variables selected are similar to those used in the works of Attfield (1985), Capps et al. (1994), and Dharmasena and Capps (2012). However, results were not encouraging since the own-price elasticities for some dairy categories had positive signs.

Seasonality Adjustment

Seasonal patterns likely are evident in purchases of dairy products. For example, ice cream tends to be consumed more in summer than in winter. To capture possible seasonality, we included elven dummies in the demand model as shown in equation (13). December is used as the base or reference category.

Empirical Results

SAS 9.4 is used to run the regressions for demand system models based on the iterated seemingly unrelated regression procedure (ITSUR). The equation of ice cream demand is dropped to avoid the singularity of the variance-covariance matrix due to the adding-up constraint. Since two lags of total expenditure are used in the instrumental regression to circumvent the endogeneity of total expenditure, the number of actual observations used in the demand systems regression is 69[17].

Goodness-of-Fit

The goodness-of-fit metrics R^2 and adjusted R^2, as well as Durbin-Watson statistics for QUADIS and Barten model, are shown in Table III-4. For QUAIDS, Greek yogurt has the largest R^2 at 0.99, and R^2 of all the other categories are above 0.90 except for plant-based milk alternatives (0.89). Durbin-Watson statistics ranged from 1.81 to 2.59 rejecting the presence of the first-order autocorrelation. For the Barten model, natural cheese has the largest R^2 at 0.97, while plant-based milk alternatives had the lowest R^2 at 0.77. The R^2 for all the other dairy categories ranged from 0.85 to 0.95. Durbin-Watson Statistics ranged from 1.49 to 2.47 rejecting the presence of the first-order autocorrelation.

Parameters

In Tables III-5 and III-6, the estimated parameters and associated p-value for QUAIDS and Barten model respectively are exhibited. For QUADIS, nineteen out of

[17] For the Barten model, 68 actual observations are used since the variables contains the difference between the log quantity and a period lag of log quantity.

forty-five gamma parameters γ_{ij}, seven out of nine alpha parameters α_i, and eight out of nine beta β_i are statistically significant at the 5% level. Seven out of nine lambda parameters λ_i are significant at the 5% level individually and jointly significant at the 5% level based on the chi-squared test (see Table III-5). These findings then reflect the presence of quadratic Engel curves. Because of the significance and joint significance of the λ_i parameters, the QUAIDS model is preferred to AIDS. The estimate of the first-order autocorrelation is specified as rho, which is statistically significant at 5% level. We included the price of margarine as an exogenous variable in the butter equation. However, the estimated coefficient associated with the price of margarine is not significant in the QUAIDS model. Last, monthly dummies are estimated to capture seasonality for each dairy category, where December is used as the base. All dairy categories except for plant-based milk alternatives show seasonal patterns based on the joint chi-squared tests. For flavored milk, white milk, non-Greek yogurt, and Greek yogurt, the month with the highest purchase is February, and the month with the lowest purchase is December. In contrast, the purchases for butter, natural cheese, and processed cheese are highest in December or January, and are lowest in February. Purchases of ice cream are highest in June and lowest in December.

For Barten's synthetic model, fifteen out of forty-five beta parameters β_{ij} and eight out of nine alpha parameters α_i are significant at 5% level. Lambda λ and mu μ are significant at the 5 % level individually. The Barten model nests four different models by imposing constraints on λ and μ. The joint test results for four null hypotheses on λ and μ presented in Table III-6 indicate that all nested models: Rotterdam, AIDS, CBS, and NBR models are not supported by our dataset. Similar to the QUAIDS model, margarine price is included in the butter equation, and the estimated coefficient associated with the price of margarine is significant at 5% level. Concerning seasonality, all of the dairy categories except for plant-based milk alternatives show seasonal patterns based on joint chi-squared tests. The month associated with the highest purchases for flavored milk, white milk, non-Greek yogurt, and Greek yogurt is February, and the months associated with the lowest purchases are May, March, January, and January respectively. Households purchase more butter and cheese (both natural and processed cheese) in November and January while purchasing less in February and April respectively. Purchases of ice cream are highest in August, and lowest in March.

Uncompensated, Compensated Price Elasticities, and Expenditure Elasticities

The uncompensated, compensated price elasticities and expenditure elasticities are calculated based on equations (4), (5) and (6) for QUAIDS, and equations (10), (11), and (12) for Barten model. These equations indicate that the respective elasticities depend not only on the estimated parameters but also on prices, total expenditures, and budget shares. The uncompensated, compensated price elasticities and expenditure elasticities calculated at the sample means for QUADIS are presented in Tables III-7 and III-8 respectively. The uncompensated, compensated price elasticities and expenditure elasticities calculated at the sample means for the Barten model are presented in Table III-9 and Table III-10 respectively. Table III-11 compares the uncompensated and compensated own-price elasticities between the QUAIDS model and the Barten model. The uncompensated and compensated own-price elasticities for both demand systems have negative signs and are statistically significant at the 5% level[18]. The results from both models indicate that most dairy categories have elastic uncompensated and compensated own-price elasticities except for white milk. Compared to the QUAIDS model, the Barten model results in larger uncompensated and compensated own-price elasticities in general. In particular, the compensated and uncompensated own-price elasticities for butter from the QUAIDS model are -1.91 and -1.80, while those from the Barten model are -3.46 and -3.33.

The expenditure elasticities for both demand systems have positive signs and are statistically significant at the 5% level. The results from both models indicate that white milk, non-Greek yogurt, Greek yogurt, and ice cream are necessities, while butter and natural cheese are luxuries. The QUAIDS model shows that flavored milk and plant-based milk alternatives are luxuries, and processed cheese is a necessity, which is on contrary to the results from the Barten model.

For QUAIDS, 31 out of 72 uncompensated and 16 out of 72 compensated cross-price elasticities are negative, while 25 out of 72 uncompensated and 14 out of 72 compensated cross-price elasticities are negative for the Barten model. Table III-12 shows details of the substitutability and complementarity among the dairy categories based on the compensated cross-price elasticities for the two models. 16 out 72 compensated cross-price elasticities from the QUAIDS model are statistically significant at the 5% level. The results indicate that white milk is complement to Greek yogurt, but white milk is substitute to natural cheese; non-Greek yogurt is complement to white milk; Greek yogurt is substitute to non-Greek yogurt and ice cream; butter is substitute to natural cheese; natural

[18] The standard errors were obtained using the delta-method.

cheese is substitute to flavored milk, white milk, non-Greek yogurt, butter, processed cheese, and ice cream; processed cheese is substitute to white milk and natural cheese; ice cream is substitutes to Greek yogurt and natural cheese. 38 out of 72 compensated cross-price elasticities from the Barten model are statistically significant at the 5% level. The results indicate that flavored milk is complement to white milk and ice cream, at the same time flavored milk is substitute to butter and natural cheese; white milk is complement to flavored milk and Greek yogurt, while white milk is substitute to butter, natural cheese, and processed cheese; non-Greek yogurt is substitute to Greek yogurt, butter, natural cheese, and processed cheese; Greek yogurt is complement to white milk, while Greek yogurt is substitute to non-Greek yogurt, butter, and plant-based milk alternatives; butter is substitute to flavored milk, white milk, non-Greek yogurt, Greek yogurt, natural cheese, and ice cream; natural cheese is substitute to flavored milk, white milk, non-Greek yogurt, butter, processed cheese, and ice cream; processed cheese is substitute to white milk, non-Greek yogurt, and natural cheese; plant-based milk alternatives are substitute to Greek yogurt and natural cheese; ice cream is substitute to butter, natural cheese, and processed cheese.

Concluding Remarks

In this study, the QUAIDS and the Barten's synthetic model have been utilized to investigate the demand for nine dairy products and dairy alternative products based on monthly time-series data through January 2010 to November 2015 from Nielsen Homescan Panel data. Issues such as serial correlation, endogeneity of total expenditure, and seasonality were addressed during the estimation. The uncompensated and compensated price elasticities as well as the expenditure elasticities, are estimated from this research.

Both models indicate that the uncompensated and compensated own-price elasticities for most dairy categories are in the elastic range except for white milk. White milk, non-Greek yogurt, plant-based milk alternatives, and ice cream are found to be necessities, while butter and natural cheese are luxuries based on results from both models. Divergences of the expenditure elasticities exist in flavored milk, plant-based milk alternatives, and processed cheese between different models. Both substitutability and complementarity are found among different dairy categories. These findings provide useful information for retailers to develop pricing strategies to maximize the revenue at least in the short run.

Further studies could be conducted in several directions. First, although a detailed comparison of the estimation results is presented in this research, we still need to determine which model is more suitable for this dataset. Since the dependent variables are different between these two models, the popular criteria such as adjusted R^2, AIC, BIC, RMSE for model selection are not applicable for this study (Meyer *et al.,* 2011). Machine learning methods such as K-fold cross-validation or Leave-one-out cross-validation might be a better way to compare these models. Second, the price variables are assumed to be exogenous during the estimation. The endogeneity of the price variables might cause biased estimation results. Future work on selecting appropriate instruments for price variables is warranted to solve this problem. Third, while ice cream as a dairy product has interrelationships between other dairy products, it is also considered to be a popular dessert in the American diet system. Including the prices of other desserts in the demand estimation for ice cream might be necessary due to its dual attribute. Fourth, another limitation is that this study is based on time-series data at the aggregated household level. The time-series data allows us to analyze the demand change over different periods, captures the short-term impacts of price on quantity, and facilitate computation. However, it fails to capture the socio-demographic characteristics of households. For future work, we plan to use the Exact Affine Stone Index (EASI) model to examining the impacts of the socio-demographic characteristics of different households.

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Table III-1Market Penetration for Different Dairy Products from 2007 to 2015

Year	White Milk	Flavored Milk	Butter	Ice Cream	Natural Cheese	Processed Cheese	Non-Greek Yogurt	Greek Yogurt	PMA[19]
2007	95%	28%	63%	86%	94%	90%	77%	0%	11%
2008	95%	27%	65%	77%	94%	90%	79%	2%	12%
2009	95%	28%	67%	76%	94%	90%	79%	5%	13%
2010	94%	28%	66%	75%	94%	90%	80%	20%	17%
2011	94%	26%	67%	72%	94%	89%	78%	35%	19%
2012	93%	25%	69%	71%	95%	89%	75%	44%	21%
2013	93%	23%	71%	72%	95%	88%	72%	53%	23%
2014	92%	21%	70%	72%	95%	87%	73%	54%	28%
2015	92%	23%	71%	71%	96%	86%	73%	54%	29%

Source: Nielsen Homescan panel, calendar years 2007 to 2015

[19] Short for plant-based milk alternatives

Table III-2 Summary Statistics of Quantities, Expenditures, Budget Shares, Unit Values, Consumption Price Index (CPI), and Income.

		Mean	Std Dev	Minimum	Maximum
Monthly Quantities (Ounces)	Flavored Milk	7.89	0.91	6.05	10.22
	White Milk	213.80	19.79	180.58	274.84
	Non-Greek Yogurt	22.54	4.09	14.26	33.06
	Greek Yogurt	6.15	3.29	0.56	10.96
	Butter	7.26	2.28	4.93	13.24
	Natural Cheese	23.64	4.19	15.64	31.65
	Processed Cheese	9.43	1.23	7.61	12.89
	PMA	8.28	1.50	5.24	11.63
	Ice Cream	23.71	3.89	17.15	33.19
Budget Share	Flavored Milk	0.01	0.00	0.01	0.02
	White Milk	0.28	0.03	0.21	0.32
	Non-Greek Yogurt	0.11	0.02	0.07	0.14
	Greek Yogurt	0.05	0.02	0.01	0.08
	Butter	0.07	0.02	0.05	0.14
	Natural Cheese	0.30	0.03	0.25	0.34
	Processed Cheese	0.10	0.01	0.08	0.13
	PMA	0.02	0.00	0.01	0.02
	Ice Cream	0.07	0.01	0.05	0.10
Unit Values ($/Ounce)	Flavored Milk	0.04	0.00	0.03	0.04
	White Milk	0.03	0.00	0.02	0.04
	Non-Greek Yogurt	0.10	0.00	0.09	0.10
	Greek Yogurt	0.18	0.01	0.16	0.21
	Butter	0.19	0.02	0.15	0.26
	Natural Cheese	0.26	0.01	0.24	0.30
	Processed Cheese	0.21	0.01	0.19	0.23
	PMA	0.05	0.00	0.04	0.05
	Ice Cream	0.06	0.00	0.05	0.07
	Margarine	0.09	0.01	0.08	0.10
Expenditure ($)	Total Expenditure	20.46	1.82	16.32	24.42
CPI (1982 -84=100)	Consumer Price Index	234.71	9.35	218.78	249.05
Per Capita Income ($)	DPI	39,618	142	37,573	41,933

Table III-3 Instrumental Estimation Results for Total Expenditure.

	Total expenditure	
Variables	Estimate	p-value
constant	-2.88	0.13
log $(DPI)_t$	0.40	0.08[20]
log $(\text{Total Expenditure})_{t-1}$	**0.31**	**0.01**
log $(\text{Total Expenditure})_{t-2}$	**0.38**	**0.00**
Goodness-of-Fit	R2	0.69
	Adjusted R2	0.67
	RMSE	0.05
	Durbin-Watson	2.17

Note: Bold numbers indicate significance at the 5% level.

[20] Statistically significant at the 10% level.

Table III-4 Goodness-of-fit metrics and Durbin-Watson Statistics for QUAIDS and Barten model.

	Category	R-Square	Adj R-Sq	Durbin-Watson
QUAIDS	Flavored Milk	0.96	0.95	2.52
	White Milk	0.97	0.96	2.59
	Non-Greek Yogurt	0.98	0.97	2.49
	Greek Yogurt	0.99	0.98	1.96
	Butter	0.92	0.89	2.30
	Natural Cheese	0.98	0.97	2.12
	Processed Cheese	0.97	0.96	2.49
	Plant-Based Milk Alternatives	0.89	0.86	1.81
	Ice Cream[21]	0.98	0.97	2.18
Barten	Flavored Milk	0.89	0.86	1.94
	White Milk	0.94	0.93	2.32
	Non-Greek Yogurt	0.93	0.91	1.92
	Greek Yogurt	0.89	0.85	1.49
	Butter	0.85	0.80	1.59
	Natural Cheese	0.97	0.96	1.71
	Processed Cheese	0.95	0.93	2.47
	Plant-Based Milk Alternatives	0.77	0.71	1.72
	Ice Cream	0.88	0.84	1.95

[21] The demand systems are re-estimated by dropping the equations associated with flavored milk to obtain the goodness-of-fit metrics for ice cream.

Table III-5 Parameter Estimates and Associated p-Values for QUAIDS.

	Parameters	Estimates	P-Value		Parameters	Estimates	P-Value
Gamma	g11[22]	**-0.02**	**0.05**	Alpha	a1	**0.23**	**0.01**
	g12	**0.03**	**0.00**		a2	**0.21**	**0.02**
	g13	**-0.15**	**0.00**		a3	**0.33**	**0.00**
	g14	0.02	0.07		a4	**0.21**	**0.03**
	g15	-0.02	0.06		a5	**0.27**	**0.00**
	g16	-0.03	0.09		a6	**0.27**	**0.00**
	g17	0.04	0.07		a7	**0.21**	**0.03**
	g18	**0.07**	**0.00**		a8	0.17	0.07
	g19	0.06	0.15		a9	-0.88	0.22
	g22	0.06	0.11				
	g23	**0.29**	**0.01**	Beta	b1	**-0.07**	**0.00**
	g24	-0.06	0.07		b2	**0.17**	**0.00**
	g25	0.05	0.05		b3	**-0.77**	**0.00**
	g26	0.04	0.24		b4	0.08	0.21
	g27	-0.10	0.06		b5	**-0.12**	**0.01**
	g28	**-0.15**	**0.00**		b6	**-0.19**	**0.01**
	g29	**-0.15**	**0.01**		b7	**0.21**	**0.05**
	g33	**-1.59**	**0.00**		b8	**0.36**	**0.00**
	g34	0.22	0.14		b9	**0.33**	**0.04**
	g35	**-0.22**	**0.02**				
	g36	**-0.36**	**0.02**				
	g37	0.43	0.10	Lambda	L1	**0.00**	**0.00**
	g38	**0.70**	**0.00**		L2	**-0.01**	**0.00**
	g39	**0.68**	**0.05**		L3	**0.04**	**0.00**
	g44	-0.06	0.08		L4	0.00	0.24
	g45	0.02	0.29		L5	**0.01**	**0.01**
	g46	0.02	0.55		L6	**0.01**	**0.01**
	g47	-0.06	0.23		L7	-0.01	0.09
	g48	-0.06	0.30		L8	**-0.02**	**0.00**
	g49	-0.05	0.46		L9	**-0.02**	**0.03**
	g55	**-0.10**	**0.01**				
	g56	-0.01	0.67				
	g57	0.07	0.13		rho	**0.96**	**0.00**
	g58	**0.11**	**0.01**		s[23]	0.00	0.46
	g59	0.10	0.11				
	g66	**-0.20**	**0.01**				
	g67	**0.17**	**0.01**				
	g68	**0.18**	**0.01**		Joint test for Lambda	Chi-Squared statistic	p-value
	g69	0.19	0.09				
	g77	-0.18	0.13				
	g78	-0.18	0.11				
	g79	-0.19	0.06			**359.8**	**0.00**
	g88	**-0.35**	**0.01**				
	g89	**-0.32**	**0.01**				
	g99	-0.32	0.24				

[22] The subscript number represents dairy categories: (1) flavored milk (mainly chocolate milk), (2) white milk (contains both organic and conventional white milk), (3) non-Greek yogurt, (4) Greek yogurt, (5) butter, (6) natural cheese, (7) processed cheese, (8) plant-based milk alternatives (PMA), (9) ice cream.
[23] Stands for coefficient associated with the price of margarine.

Table III-5 Continued

	Parameters	Estimates	p-Value		Parameters	Estimates	p-Value
Seasonality	m11	**0.001**	**0.00**	Natural Cheese	m61	**0.016**	**0.00**
Flavored Milk	m12	**0.003**	**0.00**		m62	-0.009	0.09
	m13	**0.002**	**0.00**		m63	-0.004	0.25
	m14	**0.001**	**0.00**		m64	-0.007	0.07
	m15	**0.001**	**0.00**		m65	-0.003	0.41
	m16	**0.002**	**0.00**		m66	-0.006	0.14
	m17	**0.002**	**0.00**		m67	-0.006	0.09
	m18	**0.002**	**0.00**		m68	-0.003	0.38
	m19	**0.002**	**0.00**		m69	0.002	0.64
	m110	**0.001**	**0.00**		m610	-0.004	0.33
	m111	**0.002**	**0.00**		m611	-0.004	0.32
White Milk	m21	**0.008**	**0.04**	Processed Cheese	m71	-0.003	0.20
	m22	**0.024**	**0.00**		m72	**-0.028**	**0.00**
	m23	0.001	0.88		m73	**-0.013**	**0.00**
	m24	0.006	0.10		m74	**-0.018**	**0.00**
	m25	**0.011**	**0.00**		m75	**-0.010**	**0.00**
	m26	**0.011**	**0.01**		m76	**-0.012**	**0.00**
	m27	**0.008**	**0.03**		m77	**-0.013**	**0.00**
	m28	**0.010**	**0.01**		m78	**-0.012**	**0.00**
	m29	**0.008**	**0.04**		m79	**-0.014**	**0.00**
	m210	0.007	0.07		m710	**-0.009**	**0.00**
	m211	**0.010**	**0.01**		m711	**-0.011**	**0.00**

Table III-5 Continued

	Parameters	Estimates	p-Value			Parameters	Estimates	p-Value
Non-Greek	m31	**0.006**	**0.03**	Plant-Based Milk		m81	-0.001	0.40
Yogurt	m32	**0.039**	**0.00**	Alternatives		m82	0.001	0.72
	m33	**0.016**	**0.00**	(PMA)		m83	0.001	0.52
	m34	**0.017**	**0.00**			m84	0.001	0.35
	m35	**0.014**	**0.00**			m85	0.000	0.88
	m36	**0.017**	**0.00**			m86	0.001	0.52
	m37	**0.013**	**0.00**			m87	0.000	0.93
	m38	**0.012**	**0.00**			m88	0.000	0.70
	m39	**0.017**	**0.00**			m89	0.000	0.87
	m310	**0.017**	**0.00**			m810	0.000	0.89
	m311	**0.011**	**0.00**			m811	0.001	0.60
Greek	m41	0.005	0.06	Ice Cream		m91	**0.005**	**0.01**
Yogurt	m42	**0.025**	**0.00**			m92	**0.012**	**0.00**
	m43	**0.010**	**0.00**			m93	**0.015**	**0.00**
	m44	**0.013**	**0.00**			m94	**0.015**	**0.00**
	m45	**0.010**	**0.00**			m95	**0.013**	**0.00**
	m46	**0.011**	**0.00**			m96	**0.018**	**0.00**
	m47	**0.011**	**0.00**			m97	**0.015**	**0.00**
	m48	**0.009**	**0.00**			m98	**0.014**	**0.00**
	m49	**0.012**	**0.00**			m99	**0.004**	**0.02**
	m410	**0.009**	**0.00**			m910	**0.005**	**0.00**
	m411	**0.008**	**0.00**			m911	**0.004**	**0.04**
Butter	m51	**-0.036**	**0.00**	**Joint test for**				
	m52	**-0.066**	**0.00**	**seasonality**			Chi-sqr	p-value
	m53	**-0.027**	**0.00**		Flavored Milk		**53.840**	**0.00**
	m54	**-0.028**	**0.00**		White Milk		**40.630**	**0.00**
	m55	**-0.035**	**0.00**		Non-Greek Yogurt		**157.830**	**0.00**
	m56	**-0.041**	**0.00**		Greek Yogurt		**89.200**	**0.00**
	m57	**-0.029**	**0.00**		Butter		**156.180**	**0.00**
	m58	**-0.031**	**0.00**		Natural Cheese		**84.230**	**0.00**
	m59	**-0.029**	**0.00**		Processed Cheese		**247.450**	**0.00**
	m510	**-0.027**	**0.00**		PMA		9.010	0.62
	m511	**-0.020**	**0.00**		Ice Cream		**462.970**	**0.00**

Table III-6 Parameter Estimates and Associated p-Values for the Barten Model.

	Parameters	Estimates	p-Value		Parameters	Estimates	p-Value
Beta	b11	**0.02**	**0.00**	Alpha	a1	**-0.02**	**0.00**
	b12	**-0.01**	**0.00**		a2	**-0.22**	**0.00**
	b13	0.00	0.73		a3	**-0.07**	**0.00**
	b14	0.00	0.89		a4	**-0.05**	**0.00**
	b15	**0.01**	**0.01**		a5	0.02	0.52
	b16	0.00	0.92		a6	**-0.12**	**0.01**
	b17	0.00	0.64		a7	**-0.03**	**0.04**
	b18	0.00	0.32		a8	**-0.02**	**0.00**
	b19	-0.01	0.07		a9	**-0.05**	**0.00**
	b22	**0.46**	**0.00**				
	b23	**-0.07**	**0.00**	Lambda	L	**1.57**	**0.00**
	b24	**-0.05**	**0.00**	Mu	mu	**2.61**	**0.00**
	b25	-0.02	0.30		s1[24]	**0.00**	**0.00**
	b26	**-0.19**	**0.00**				
	b27	**-0.06**	**0.00**	**Joint test**	H0	chi-sqr stat	p-value
	b28	**-0.01**	**0.00**	Rotterdam	L=0,mu=0	**201.33**	**0.00**
	b29	**-0.05**	**0.00**	ADIS	L=1,mu=1	**38.85**	**0.00**
	b33	0.09	0.06	CBS	L=1,mu=0	**67.92**	**0.00**
	b34	0.02	0.22	NBR	L=0,mu=1	**166.72**	**0.00**
	b35	**0.04**	**0.00**				
	b36	-0.03	0.12				
	b37	0.02	0.06				
	b38	-0.01	0.11				
	b39	**-0.05**	**0.00**				
	b44	0.00	0.97				
	b45	0.02	0.07				
	b46	-0.02	0.24				
	b47	0.01	0.45				
	b48	0.01	0.09				
	b49	0.02	0.24				
	b55	-0.06	0.16				
	b56	0.02	0.25				
	b57	**-0.02**	**0.02**				
	b58	0.00	0.57				
	b59	0.01	0.14				
	b66	**0.22**	**0.02**				
	b67	0.01	0.67				
	b68	0.00	0.55				
	b69	-0.02	0.32				
	b77	0.02	0.55				
	b78	0.00	0.83				
	b79	0.01	0.32				
	b88	0.01	0.48				
	b89	0.00	0.71				
	b99	**0.08**	**0.03**				

[24] Stands for coefficient associated with the price of margarine.

Table III-6 Continued.

	Parameters	Estimates	p-Value		Parameters	Estimates	p-Value
Seasonality	m11	**-0.001**	**0.04**	Natural	m61	**0.018**	**0.00**
Flavored	m12	**0.001**	**0.02**	Cheese	m62	0.001	0.55
Milk	m13	**0.000**	**0.09**		m63	-0.002	0.22
	m14	**0.000**	**0.11**		m64	**-0.015**	**0.00**
	m15	**-0.001**	**0.01**		m65	0.001	0.82
	m16	**0.000**	**0.34**		m66	**-0.010**	**0.00**
	m17	**0.000**	**0.04**		m67	0.002	0.24
	m18	**0.000**	**0.32**		m68	**-0.004**	**0.04**
	m19	**0.000**	**0.06**		m69	-0.002	0.35
	m110	**-0.001**	**0.02**		m610	-0.001	0.50
	m111	**0.001**	**0.01**		m611	**0.004**	**0.04**
White	m21	**-0.001**	**0.62**	Processed	m71	**0.010**	**0.00**
Milk	m22	**0.011**	**0.00**	Cheese	m72	**0.004**	**0.00**
	m23	**-0.013**	**0.00**		m73	0.001	0.52
	m24	0.004	0.16		m74	**-0.012**	**0.00**
	m25	-0.004	0.09		m75	-0.002	0.12
	m26	-0.001	0.74		m76	**-0.009**	**0.00**
	m27	-0.004	0.07		m77	0.002	0.18
	m28	0.001	0.61		m78	0.001	0.34
	m29	0.000	0.86		m79	0.001	0.69
	m210	**-0.007**	**0.00**		m710	0.000	0.77
	m211	0.001	0.80		m711	-0.002	0.17

Table III-6 Continued.

	Parameters	Estimates	p-Value			Parameters	Estimates	p-Value
Non-	m31	**-0.010**	**0.00**	Plant-Based		m81	-0.001	0.19
Greek	m32	**0.021**	**0.00**	Milk		m82	-0.001	0.12
Yogurt	m33	0.002	0.28	Alternatives		m83	0.000	0.79
	m34	**0.005**	**0.04**			m84	0.001	0.25
	m35	-0.003	0.16			m85	0.000	0.70
	m36	-0.002	0.31			m86	**0.001**	**0.01**
	m37	-0.003	0.09			m87	-0.001	0.22
	m38	**-0.004**	**0.04**			m88	0.001	0.13
	m39	0.001	0.51			m89	0.000	0.36
	m310	0.000	0.87			m810	0.001	0.20
	m311	**-0.005**	**0.01**			m811	0.000	0.81
Greek	m41	**-0.004**	**0.01**	Ice Cream		m91	**-0.005**	**0.00**
Yogurt	m42	**0.014**	**0.00**			m92	**-0.005**	**0.00**
	m43	0.001	0.41			m93	**-0.007**	**0.00**
	m44	**0.006**	**0.00**			m94	-0.003	0.16
	m45	0.001	0.61			m95	**0.006**	**0.00**
	m46	0.001	0.70			m96	**0.007**	**0.00**
	m47	0.000	0.78			m97	**0.003**	**0.03**
	m48	0.000	0.87			m98	**0.007**	**0.00**
	m49	0.002	0.24			m99	**0.004**	**0.00**
	m410	-0.001	0.46			m910	**0.003**	**0.02**
	m411	-0.002	0.08			m911	**-0.007**	**0.00**
Butter	m51	-0.005	0.34	**Joint test for**				
	m52	**-0.015**	**0.04**	**seasonality**			chi-sqr	p-value
	m53	0.006	0.26		Flavored Milk		**34.940**	**0.00**
	m54	-0.003	0.54		White Milk		**44.050**	**0.00**
	m55	0.002	0.73		Non-Greek Yogurt		**107.510**	**0.00**
	m56	-0.001	0.83		Greek Yogurt		**71.740**	**0.00**
	m57	0.007	0.14		Butter		**32.370**	**0.00**
	m58	0.003	0.52		Natural Cheese		**149.480**	**0.00**
	m59	0.004	0.40		Processed Cheese		**140.250**	**0.00**
	m510	**0.012**	**0.01**		PMA		17.150	0.10
	m511	**0.016**	**0.00**		Ice Cream		**196.620**	**0.00**

Table III-7 Uncompensated Own-Price and Crosse Elasticities as well as Expenditure Elasticities for the QUAIDS.

	Flavored Milk	White Milk	Non-Greek Yogurt	Greek Yogurt	Butter	Natural Cheese	Processed Cheese	PMA	Ice Cream	Expenditure Elasticity
Flavored Milk	**-1.17**	0.01	0.03	0.11	-0.07	0.01	-0.03	-0.18	-0.02	**0.99**
	(0.00)	(0.59)	(0.73)	(0.15)	(0.44)	(0.50)	(0.60)	(0.30	(0.74)	(0.00)
White Milk	**-0.28**	**-0.45**	-0.17	**-0.47**	**-0.52**	**-0.13**	-0.17	-0.32	-0.12	**0.78**
	(0.01)	(0.00)	(0.33)	(0.00)	(0.02)	(0.00)	(0.07)	(0.09	(0.15)	(0.00)
Non-Greek	0.15	**-0.42**	**-1.34**	0.81	1.13	0.11	0.10	0.10	-0.23	**0.98**
	(0.68)	(0.01)	(0.00)	(0.14)	(0.11)	(0.37)	(0.67)	(0.89	(0.44)	(0.00)
Greek Yogurt	0.35	-0.04	**0.47**	**-2.09**	-0.15	-0.04	-0.08	0.72	**0.38**	**0.91**
	(0.12)	(0.63)	(0.02)	(0.00)	(0.59)	(0.55)	(0.59)	(0.11	(0.05)	(0.00)
Butter	0.04	0.00	0.12	0.03	**-1.91**	**0.14**	0.07	0.19	-0.07	**1.62**
	(0.78)	(0.96)	(0.30)	(0.88)	(0.00)	(0.02)	(0.41)	(0.41	(0.54)	(0.00)
Natural Cheese	0.33	-0.02	0.16	-0.11	0.38	**-1.39**	**0.68**	0.29	0.15	**1.04**
	(0.15)	(0.83)	(0.40)	(0.75)	(0.36)	(0.00)	(0.00)	(0.52	(0.48)	(0.00)
Processed	-0.17	0.13	0.08	-0.06	-0.39	**0.19**	**-1.73**	0.13	-0.01	**1.02**
	(0.54)	(0.21)	(0.75)	(0.87)	(0.38)	(0.02)	(0.00)	(0.79	(0.95)	(0.00)
PMA	-0.21	0.01	-0.03	0.29	-0.01	0.02	0.05	**-2.39**	0.06	**1.18**
	(0.31)	(0.85)	(0.81)	(0.09)	(0.96)	(0.56)	(0.60)	(0.00	(0.66)	(0.02)
Ice Cream	-0.03	0.00	-0.29	0.58	-0.07	0.05	0.07	0.28	**-1.26**	**1.13**
	(0.93)	(0.99)	(0.15)	(0.04)	(0.79)	(0.40)	(0.67)	(0.60	(0.00)	(0.00)

Table III-8 Compensated Own-Price and Cross-Price Elasticities for the QUAIDS.

	Flavored Milk	White Milk	Non-Greek Yogurt	Greek Yogurt	Butter	Natural Cheese	Processed Cheese	PMA	Ice Cream
Flavored Milk	**-1.16**	0.03	0.04	0.12	-0.05	0.02	-0.01	-0.16	-0.01
	(0.00)	(0.34)	(0.58)	(0.10)	(0.58)	(0.09)	(0.79)	(0.34	(0.92)
White Milk	-0.01	**-0.24**	0.10	-0.22	-0.07	**0.16**	0.12	0.01	0.19
	(0.92)	(0.00)	(0.54)	(0.16)	(0.73)	(0.00)	(0.18)	(0.97	(0.03)
Non-Greek	0.26	**-0.34**	**-1.24**	0.90	1.30	0.22	0.21	0.22	-0.11
	(0.50)	(0.05)	(0.01)	(0.11)	(0.08)	(0.10)	(0.41)	(0.75	(0.72)
Greek Yogurt	0.40	0.00	**0.52**	**-2.04**	-0.06	0.02	-0.02	0.78	**0.44**
	(0.07)	(1.00)	(0.01)	(0.00)	(0.81)	(0.76)	(0.86)	(0.08	(0.02)
Butter	0.10	0.06	0.18	0.10	**-1.80**	**0.21**	0.14	0.27	0.01
	(0.40)	(0.32)	(0.09)	(0.65)	(0.00)	(0.00)	(0.10)	(0.23	(0.92)
Natural Cheese	**0.63**	**0.21**	**0.45**	0.16	**0.86**	**-1.08**	**0.98**	0.65	**0.48**
	(0.01)	(0.02)	(0.01)	(0.62)	(0.02)	(0.00)	(0.00)	(0.14	(0.02)
Processed Cheese	-0.07	**0.20**	0.17	0.03	-0.24	**0.29**	**-1.63**	0.24	0.09
	(0.79)	(0.04)	(0.45)	(0.93)	(0.57)	(0.00)	(0.00)	(0.61	(0.65)
PMA	-0.19	0.03	-0.01	0.31	0.02	0.04	0.07	**-2.37**	0.08
	(0.35)	(0.66)	(0.92)	(0.07)	(0.92)	(0.23)	(0.47)	(0.00	(0.55)
Ice Cream	0.04	0.05	-0.22	**0.64**	0.04	**0.12**	0.14	0.36	**-1.18**
	(0.88)	(0.50)	(0.27)	(0.02)	(0.88)	(0.03)	(0.37)	(0.48	(0.00)

Table III-9 Uncompensated Own-Price and Cross-Price Elasticities and Expenditure Elasticities for the Barten's Synthetic Model.

	Flavored Milk	White Milk	Non-Greek Yogurt	Greek Yogurt	Butter	Natural Cheese	Processed Cheese	PMA	Ice Cream	Expenditure Elasticity
Flavored	**-1.11**	**-0.03**	0.01	0.04	**0.13**	0.02	0.00	-0.12	-0.09	**0.48**
	(0.00)	(0.00)	(0.84)	(0.55)	(0.00)	(0.07)	(1.00)	(0.42)	(0.14)	(0.03)
White	**-0.47**	**-0.42**	**-0.22**	**-0.50**	-0.05	**-0.22**	**-0.19**	-0.12	**-0.20**	**0.76**
	(0.00)	(0.00)	(0.01)	(0.00)	(0.84)	(0.00)	(0.01)	(0.40)	(0.05)	(0.00)
Non-	0.11	**-0.07**	**-1.56**	**0.56**	**0.65**	0.05	**0.40**	-0.48	**-0.55**	**0.87**
	(0.75)	(0.01)	(0.00)	(0.04)	(0.00)	(0.38)	(0.00)	(0.26)	(0.02)	(0.00)
Greek	0.14	**-0.10**	0.25	**-2.52**	**0.30**	0.01	0.17	0.68	0.32	**0.55**
	(0.54)	(0.00)	(0.06)	(0.00)	(0.05)	(0.80)	(0.20)	(0.04)	(0.11)	(0.01)
Butter	**0.74**	0.07	**0.49**	**0.50**	**-3.46**	**0.16**	-0.14	0.25	**0.32**	**1.90**
	(0.00)	(0.13)	(0.00)	(0.01)	(0.00)	(0.00)	(0.14)	(0.18)	(0.02)	(0.00)
Natural	**0.66**	**-0.12**	0.22	0.26	**0.49**	**-1.43**	**0.51**	**0.85**	0.28	**1.16**
	(0.01)	(0.00)	(0.17)	(0.40)	(0.05)	(0.00)	(0.00)	(0.02)	(0.24)	(0.00)
Processed	0.07	-0.02	**0.40**	0.38	-0.27	**0.17**	**-2.22**	0.27	0.35	**1.21**
	(0.81)	(0.31)	(0.00)	(0.12)	(0.06)	(0.00)	(0.00)	(0.39)	(0.06)	(0.00)
PMA	-0.17	-0.01	-0.09	**0.25**	0.04	0.04	0.04	**-2.17**	0.08	**0.53**
	(0.43)	(0.18)	(0.23)	(0.04)	(0.41)	(0.07)	(0.52)	(0.00)	(0.52)	(0.00)
Ice Cream	-0.45	-0.05	**-0.37**	0.47	0.26	0.04	0.23	0.32	**-1.35**	**0.86**
	(0.17)	(0.06)	(0.02)	(0.09)	(0.08)	(0.41)	(0.08)	(0.49)	(0.00)	(0.00)

Table III-10 Compensated Own-Price and Cross-Price Elasticities for the Barten's Synthetic Model

	Flavored Milk	White Milk	Non-Greek Yogurt	Greek Yogurt	Butter	Natural Cheese	Processed Cheese	PMA	Ice Cream
Flavored	**-1.10**	**-0.02**	0.02	0.05	**0.16**	**0.04**	0.02	-0.12	**-0.08**
	(0.00)	(0.00)	(0.63)	(0.47)	(0.00)	(0.00)	(0.68)	(0.45)	(0.20)
White Milk	**-0.33**	**-0.21**	0.03	**-0.35**	**0.48**	**0.10**	**0.14**	0.02	0.03
	(0.00)	(0.00)	(0.71)	(0.01)	(0.01)	(0.00)	(0.03)	(0.87)	(0.71)
Non-Greek	0.16	0.01	**-1.47**	**0.62**	**0.85**	**0.17**	**0.53**	-0.42	-0.46
	(0.63)	(0.71)	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.32)	(0.06)
Greek	0.16	**-0.06**	**0.29**	**-2.49**	**0.40**	0.07	0.23	**0.70**	0.36
	(0.47)	(0.01)	(0.03)	(0.00)	(0.01)	(0.16)	(0.08)	(0.04)	(0.07)
Butter	**0.77**	**0.12**	**0.55**	**0.54**	**-3.33**	**0.24**	-0.06	0.28	**0.38**
	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.53)	(0.13)	(0.01)
Natural	**0.80**	**0.10**	**0.48**	0.42	**1.06**	**-1.09**	**0.87**	**1.01**	**0.53**
	(0.00)	(0.00)	(0.00)	(0.16)	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
Processed	0.12	**0.05**	**0.49**	0.44	-0.09	**0.28**	**-2.11**	0.32	0.44
	(0.68)	(0.03)	(0.00)	(0.08)	(0.53)	(0.00)	(0.00)	(0.31)	(0.02)
PMA	-0.16	0.00	-0.08	**0.26**	0.08	**0.06**	0.06	**-2.16**	0.10
	(0.45)	(0.87)	(0.32)	(0.04)	(0.13)	(0.01)	(0.31)	(0.00)	(0.44)
Ice Cream	-0.42	0.01	-0.31	0.51	**0.39**	**0.13**	**0.32**	0.36	**-1.29**
	(0.20)	(0.71)	(0.06)	(0.07)	(0.01)	(0.02)	(0.02)	(0.44)	(0.00)

Table III-11 Comparison of Compensated and Uncompensated Own-Price Elasticities and Expenditure Elasticities Between the QUAIDS Model and the Barten Model

		QUAIDS	Barten
Uncompensated	Flavored Milk	-1.17	-1.11
	White Milk	-0.45	-0.42
	Non-Greek Yogurt	-1.34	-1.56
	Greek Yogurt	-2.09	-2.52
	Butter	-1.91	-3.46
	Natural Cheese	-1.39	-1.43
	Processed Cheese	-1.73	-2.22
	PMA	-2.39	-2.17
	Ice Cream	-1.26	-1.35
Compensated	Flavored Milk	-1.16	-1.10
	White Milk	-0.24	-0.21
	Non-Greek Yogurt	-1.24	-1.47
	Greek Yogurt	-2.04	-2.49
	Butter	-1.8	-3.33
	Natural Cheese	-1.08	-1.09
	Processed Cheese	-1.63	-2.11
	PMA	-2.37	-2.16
	Ice Cream	-1.18	-1.29
Expenditure	Flavored Milk	0.99	0.48
	White Milk	0.78	0.76
	Non-Greek Yogurt	0.98	0.87
	Greek Yogurt	0.91	0.55
	Butter	1.62	1.90
	Natural Cheese	1.04	1.16
	Processed Cheese	1.02	1.21
	PMA	1.18	0.53
	Ice Cream	1.13	0.86

Table III-12 Substitutability and Complementarity among dairy categories for the QUAIDS Model and the Barten Model.

QUAIDS	Flavored	White Milk	Non-Greek	Greek	Butter	Natural	Processed	PMA	Ice Cream
Flavored Milk		substitutes	substitutes	substitutes	complemen	substitutes	complements	complemen	complement
White Milk	complement		substitutes	**complemen**	complemen	**substitutes**	substitutes	substitutes	substitutes
Non-Greek	substitutes	**complemen**		substitutes	substitutes	substitutes	substitutes	substitutes	complement
Greek Yogurt	substitutes	substitutes	**substitutes**		complemen	substitutes	complements	substitutes	**substitutes**
Butter	substitutes	substitutes	substitutes	substitutes		**substitutes**	substitutes	substitutes	substitutes
Natural Cheese	**substitutes**	**substitutes**	**substitutes**	substitutes	**substitutes**		**substitutes**	substitutes	**substitutes**
Processed	complement	**substitutes**	substitutes	substitutes	complemen	**substitutes**		substitutes	substitutes
PMA	complement	substitutes	complements	substitutes	substitutes	substitutes	substitutes		substitutes
Ice Cream	substitutes	substitutes	complements	**substitutes**	substitutes	**substitutes**	substitutes	substitutes	
Barten	Flavored	White Milk	Non-Greek	Greek	Butter	Natural	Processed	PMA	Ice Cream
Flavored Milk		**complemen**	substitutes	substitutes	**substitutes**	**substitutes**	substitutes	complemen	**complemen**
White Milk	**complemen**		substitutes	**complemen**	**substitutes**	**substitutes**	**substitutes**	substitutes	substitutes
Non-Greek	substitutes	substitutes		**substitutes**	**substitutes**	**substitutes**	**substitutes**	complemen	complement
Greek Yogurt	substitutes	**complemen**	**substitutes**		**substitutes**	substitutes	substitutes	**substitutes**	substitutes
Butter	**substitutes**	**substitutes**	**substitutes**	**substitutes**		**substitutes**	complements	substitutes	**substitutes**
Natural Cheese	**substitutes**	**substitutes**	**substitutes**	substitutes	**substitutes**		**substitutes**	**substitutes**	**substitutes**
Processed	substitutes	**substitutes**	**substitutes**	substitutes	complemen	**substitutes**		substitutes	substitutes
PMA	complement	substitutes	complements	**substitutes**	substitutes	**substitutes**	substitutes		substitutes
Ice Cream	complement	substitutes	complements	substitutes	**substitutes**	**substitutes**	**substitutes**	substitutes	

CHAPTER IV

IMPACTS OF HOUSEHOLD SOCIO-DEMOGRAPHIC FACTORS AND ECONOMIC FACTORS ASSOCIATED WITH THE PURCHASE OF DAIRY PRODUCTS

Introduction

Background

Dairy product is an important component of the American diet. Dairy foods contain vital nutrients for the health and maintenance of the human body. The notable nutrients include calcium, vitamin D, protein, and potassium. Especially, dairy products are the primary source of calcium in the American diet, which plays an important role in improving bone health (ChooseMyPlate.gov, Dec 14, 2018). ChooseMyPlate of the United States Department of Agriculture (USDA) suggests that diets containing 3 cups of dairy products per day can improve bone mass. At the same time, low-fat and fat-free dairy foods also are of interest with consumers concerned more and more about their health conditions, especially obesity. The major dairy products consumed in the United States include fluid milk, cheese, butter, yogurt, and ice cream. The quarterly/annual per capita consumptions of different dairy products are exhibited in Figure 1-6 based on USDA, Economic Research Service, and Statista dataset. Although the consumption of total dairy products has been increasing in the U.S. dairy market, per capita consumption of fluid milk (including skim milk, 1% milk, 2 % milk, and whole milk) has shown a declining downward trend. Meanwhile, per capita consumption of cheese (both natural cheese and processed cheese), butter, and yogurt (both Greek yogurt and non-Greek yogurt) has been on an increasing upward trend. The per capita consumption of low-fat ice cream is quite stable over the last two decades, but regular ice cream has shown a slowly declining trend since 2000.

Based on the Nielsen Homescan panel data, the market penetration for different dairy products from 2007 to 2015 are exhibited in Table IV-1. The market penetration for white milk, flavored milk, ice cream, processed cheese, and non-Greek yogurt has been decreasing since 2007. The market penetration for butter and natural cheese shows slight upward trend. The market penetration of Greek yogurt has increased to 54% in 2015 since its first appearance in 2007. More plant-based milk alternatives have been offered to U.S. consumers in the past ten years (Dharmasena and Capps, 2014). The market penetration of plant-based milk alternatives has increased from 11% in 2007 to 29% in 2015.

Objectives

The general objective of this study is to estimate the demand for dairy products and dairy alternative products at the household level based on balanced annual panel data for calendar years 2010[25] to 2015[26].

The specific objectives are as follows:

(1) To examine household demand for thirteen different dairy products in the United States and household response to price and income changes. In this study, own-price elasticities, cross-price elasticities, and income elasticities for the dairy

[25] Calendar year 2010 is selected as the start of the panel data set because the market shares for Greek yogurt are relative small (<1%) compared to other dairy categories before 2010.
[26] Calendar year 2015 is selected as the end of the panel data set, because the dataset for calendar year 2015 is the most recent data set available for analysis in the Agribusiness, Food, and Consumer Economics Research Center in the Department of Agricultural Economics at Texas A&M University.

complex are estimated.

(2) To estimate the impacts of socio-demographic factors on the demand for the granular array of dairy products. In this study, two-way random effect model is used to deal with the impacts of unobserved factors.

(3) To provide a robustness check to the cross-sectional and time-series analyses based on the same Nielsen Homescan Panel data.

Few panel datasets have been used in the demand analysis for dairy complex in extant literature. The most recent demand analysis associated with different dairy categories was done in 2010 (Davis, Dong, Blayney, and Owens, 2010). Their study used a cross-sectional data from Nielsen Homescan panel for calendar year 2007. Although the cross-sectional study could provide a static analysis for the price and income elasticities as well as the marginal impacts of the socio-demographic factors on the demand of the dairy complex, a panel data analysis could provide more accurate inference of the model parameters, control heterogeneity of cross-section units over time, and mitigate the impact of the omitted variables (Baltagi, 2001). Thus, the demand analysis on the dairy complex based on a panel dataset is warranted.

Literature Review

Many studies concerning the demand for dairy products have been done in the extant literature. Most previous studies are conducted based on cross-sectional and time-series datasets.

Heien and Wessells (1988) estimated an AIDS model with 12 food items based on the Household Food Consumption Survey, a cross-sectional data set over the period 1977 to 1978. Own-price elasticities for milk (-0.63), butter (-0.73), and cheese (-0.52) were found to be in the inelastic range. Socio-economic characteristics of the household estimated in this study included urbanization, region, tenancy of the residents, number and age of people living in the household, race of the respondent, recipients of food stamps, frequency of major food shopping occasions, and classification of household by gender of the head. Their findings showed that most of these demographic variables have statistically significant impacts on the demand for milk, cheese, and butter.

Yen (2002) used a censored translog model to estimate the demand for household fat and oil demand with cross-sectional data from 1987-1988. Compensated and uncompensated own-price elasticities of butter were found to be -1.161 and -1.132 respectively.

Davis *et al.* (2009) applied a censored translog demand system model to analyze the purchases of three ice cream product categories based on a cross-sectional data set from Nielsen Homescan retail data for the calendar year 2005. Household socio-demographic factors, such as marital status, age, race, education, female employment status, and location were considered in this study. The results revealed that the uncompensated own-price elasticity for bulk ice cream was unitary. Price and consumer income were the main determinants of demand for ice cream products. Several demographic variables played important roles in the demand for ice cream such as employment status of the female head of the household, region, race, marital status, children present in the home, and education status of the female head.

Davis et al. (2010) estimated a demand system for twelve dairy products and margarine using a censored AIDS model and a cross-sectional data set from Nielsen Homescan data for calendar year 2007. As well, demographic variables were included in the model. Ten of the twelve uncompensated and compensated own-price elasticities were statistically significant. The compensated and uncompensated own-price elasticities were estimated to be -0.77 and -0.91 for bulk ice cream, -1.21 and -1.21 for sherbet/ice milk, -1.08 and -1.19 for refrigerated yogurt, -1.26 and -1.26 for frozen yogurt, -1.72 and -1.73 for drinkable yogurt, -1.65 and -1.70 for whole milk, -1.26 and -1.57 for reduced-fat milk, -1.31 and -1.32 for canned milk, -1.61 and -1.73 for natural cheese, -0.89 and -0.99 for processed cheese, -1.64 and -1.68 for cottage cheese, -1.81 and -1.87 for butter, -0.90 and -0.95 for margarine. Substitution relationships among ice cream, reduced-fat milk, and natural cheese were evident. For socio-demographic variables, household size positively influenced the purchases of ice milk, drinkable yogurts, whole milk, reduced-fat milk, processed cheese, and margarine. As well, purchases of bulk ice cream, frozen yogurt, canned milk, cottage cheese, and butter were positively influenced by the age of the female head of the household.

Davis *et al.* (2011) identified price and socio-demographic factors that affect the demand for cheese using a censored AIDS model based on a cross-sectional data set from Nielsen Homescan retail data for the calendar year 2006. The own-price elasticities of natural cheese and processed cheese were estimated to be -1.84 and -1.63 respectively. Both types of cheese were found to be substitutes. Demographic variables had statistically significant impacts on natural, cottage, processed, and grated cheeses such as household size.

Keller (2018) developed twelve different probit models to estimate the effects of socio-economic and demographic factors concerning the propensity of purchasing Greek yogurt and non-Greek yogurt with and without reference to brands using a cross-sectional data from Nielsen Homescan panel data for the calendar year 2015. Prices and income had significant effects on every profile associated with purchasing any type of yogurt. Socio-demographic variables varied depending on the types of yogurt products. The results showed that socio-demographic variables such as region, race, education status, presence of children, and age of household head impacted the demand for Greek yogurt and non-Greek yogurt.

The literatures mentioned above used cross-sectional data to conduct static analyses of different dairy products. Some other studies tried to analyze the changes of the demand for dairy complex based on time-series data sets at the aggregated over household level.

Maynard and Liu (1999) estimated the demand for dairy products including white milk, flavored milk, cheese, butter, yogurt, ice cream, and novelties using a double-log model, a linearized AIDS model, and a nested differential demand model based on weekly Nielsen Homescan retail data at aggregated over household level for the years 1996 through 1998. Most of the own-price elasticities estimated from all three models were found to be in the elastic range, different from previous studies. At the same time, the household level data were aggregated to national levels, but in doing so, this aggregation failed to capture the demographic effects.

In order to take into account both the socio-demographic effects and the time effects, some extant literatures used panel data sets to conduct the demand analyses for some individual dairy products.

Gould (1996) estimated own-price and cross-price elasticities for whole milk, 2 percent milk, and skim milk based on Nielsen Marketing Research household level panel data from April 1991 to March 1992. A demand system was estimated derived from the indirect translog utility function; demographic variables also were included in the analysis. Findings from this study found that the own-price elasticities of whole milk (-0.803), skim milk (-0.593), and 2% milk (-0.512) to be inelastic. As well, milk beverages with different fat levels were found to be substitutes.

Capps, and Ishdorj (2013) estimated the demands for 14 different cheese varieties using a censored random effect panel Tobit model based on Nielsen Homescan panel data for calendar years 2005 and 2006. The 14 cheese varieties included Mozzarella, Colby, Cheddar, Swiss, the remaining natural cheese, processed slices, loaves, snack cheese, cream cheese, Ricotta, grated cheese, specialty/imported cheese, shredded cheese, and cottage cheese. The demands for natural cheese varieties generally were found to be elastic, while most processed cheese varieties were found to be inelastic. At the same time, most of the varieties were revealed to be normal goods except for processed slices. The results showed that demographic factors, such as household size, education status, and race affected household demand for natural and processed cheeses.

These studies based on panel data sets have provided detailed analyses on individual dairy products, notably cheese and milk. However, they failed to capture the interrelationships among the demand of different dairy products.

Analytical framework

In this study, panel data from the Nielsen Homescan Panel for the calendar year 2010 to 2015 are used to conduct demand analysis of the dairy complex. The dairy complex includes seven main categories: (1) fluid milk; (2) butter; (3) margarine; (4) cheese; (5) ice cream; (6) yogurt; and (7) plant-based milk alternatives. Furthermore, the category of fluid milk is divided into three sub-categories: organic white milk, non-organic white milk, and flavored milk (mainly chocolate milk). Three sub-categories are included in the non-organic white milk category: whole milk, low-fat milk (1% and 2%), and skim milk. The category cheese is divided into two sub-categories: processed cheese and natural cheese. The category of yogurt also is divided into two sub-categories: Greek yogurt and non-Greek yogurt. Plant-based milk alternatives are included in the dairy complex because products such as soymilk and almond milk have been gaining more attention from consumers. Plant-based milk alternatives are hypothesized to be substitutes for conventional white milk. In this study, products of two brands- Blue Diamond and Silk are used to represent plant-based milk alternatives, since these two brands have the largest market shares in this category. Margarine is also included in the dairy complex because of its expected relationship with butter, although it is not a dairy product. So thirteen products will be analyzed, namely organic white milk, whole milk, low-fat milk, skim milk, flavored milk, butter, margarine, processed cheese, natural cheese, Greek yogurt, non-

Greek yogurt, ice cream, plant-based milk alternatives. A schematic depicting all thirteen dairy and dairy alternative products is shown in Figure 7.

Fixed Effect and Random Effect Models

The simplest demand model could be used is the pooled regression using ordinary least squares (OLS), which could be specified as follows:

$$y_{it} = \alpha + X_{it}'\beta + \varepsilon_{it}. \tag{1}$$

where

y_{it} = observed dependent variables representing the consumed quantity of good i for year t.

X_{it} = a vector of exogenous variables that affect consumed quantity.

β = a vector of parameters in the demand function

ε_{it} = random errors.

In this model, the parameters are assumed to be constant over time and over individuals. However, this assumption is usually violated in the panel data analysis. To deal with this problem, the heterogeneous panel regression model is usually used (Hsiao, 2007). The panel regression models could examine the group effects, time effects, or both to deal with heterogeneity or individual effects that may not be observed. These effects could be specified as a random effect or fixed effect. “For fixed effect model, the intercepts vary across the group, while a random effect model explores differences in error variance components across the individual.” (Park, 2011) In our study, both the individual effects and time effects are examined, thus two-way random effect[27] model and mixed effects model are considered. The functional forms are as follows:

The Two-way Random Effects Model:

$$y_{it} = \alpha + X'_{it}\beta + (u_i + v_t + \varepsilon_{it}) \quad (2)$$

The Mixed Effects Model:

$$y_{it} = (\alpha + v_t) + X'_{it}\beta + (u_i + \varepsilon_{it}) \quad (3)$$

where v_t is a fixed or a random time effect, u_i is a random individual effect specific to unobserved variables, and ε_{it} are independent identically distributed error terms, $\varepsilon_{it} \sim iid(0, \sigma^2)$. Furthermore, in mixed effects model, v_t stands for the individual-invariant effects, which is allowed to be correlated with other regressors. The fixed time effect could be estimated by least squares dummy variable (LSDV) regression. In two-way random effect model, the individual effect u_i and the time effect v_t should not be correlated with other regressors. A two-way random effect model could be estimated by generalized least squares (GLS).

Tests for Fixed Effects and Random Effects

When estimating the demand model, it should be determined which is the appropriate one, a pooled OLS model, the mixed effects model, or the two-way random effects model. The following tests could be implemented to help make the decision.

[27] Two-way fixed effect models are not feasible for our study, because the data set contains 28,109 households, which means in order to control for the group effect, 28,109 dummy variables would be generated during the estimation in the fixed effect model. It will bring a severe loss of degree of freedom.

F test

Fixed effects could be tested by the F test. Because fixed effects are individual-invariant effects, OLS with a set of dummies, known as least squares dummy variable regression (LSDV) could be applied as the estimation process. Thus, the joint significance of the parameters for these dummies could be tested to examine the existence of fixed effects, which is known as the F test with null hypothesis H0: $\gamma_1 = \gamma_2 = \cdots = \gamma_T = 0$. γ_t is the parameter of the dummy representing year t.

The Lagrange multiplier test

Random effects could be tested by the Breusch and Pagan Lagrange multiplier test. Breusch and Pagan Lagrange multiplier test examines if individual (or time) specific variance components are zero. According to Breusch and Pagan (1980) and Baltagi (2001), assume $\widehat{e_{it}}$ is the residual for household i and year t from the pooled OLS regression, then the BP test for random effect model is

$$BP = \frac{NT}{2(T-1)}\left[\frac{\sum_{i=1}^{N}\left[\sum_{t=1}^{T}\widehat{e_{it}}\right]^2}{\sum_{i=1}^{N}\sum_{t=1}^{T}\widehat{e_{it}}^2} - 1\right]^2 \quad (4)$$

The BP statistics follows a χ^2 distribution with p-1 degrees of freedom, and p is the number of parameters. The null hypothesis is H0: no random effects. For specification, H0: $\sigma_u^2 = 0$ for individual effect. σ_u^2 is the variance of u_i; H0: $\sigma_v^2 = 0$ for time effect. σ_v^2 is the variance of v_t. If the null hypothesis is not rejected in either F test or BP test, the pooled OLS is favored.

The Hausman test

The Hausman test (Hausman, 1978) compares the two-way random effect model to the mixed-effect model. Consider two estimators $\widehat{\beta_e}$ and $\widehat{\beta_c}$, The null hypothesis is H0: both estimators are consistent, but only $\widehat{\beta_e}$ is efficient. The alternative hypothesis is H1: only $\widehat{\beta_c}$ is consistent. The m statistics is

$$m = \left(\widehat{\beta_e} - \widehat{\beta_c}\right)' \left[\widehat{\Sigma_e} - \widehat{\Sigma_c}\right]^{-1} \left(\widehat{\beta_e} - \widehat{\beta_c}\right) \quad (5)$$

where $\widehat{\Sigma_e}$ and $\widehat{\Sigma_c}$ are estimates of the covariance matrices of $\widehat{\beta_e}$ and $\widehat{\beta_c}$. The m statistics follows a χ^2distribution with k degrees of freedom, where k is the rank of $\left[\widehat{\Sigma_e} - \widehat{\Sigma_c}\right]^{-1}$. In our case, the null hypothesis is H0: the mixed effects estimator is consistent but inefficient, while the random effect estimator is both consistent and efficient. Failure to rejecting the null hypothesis favors the random effect model.

Data

The panel data correspond to a set of annual data from 2010 to 2015 at the household level. This data set contains the annual expenditure, quantity, and unit values of thirteen dairy products purchased by each household who has remained in the survey from 2010 to 2015. Totally, 28,109 households are considered, and thus 168,654 purchasing records are used for analysis. Additionally, the socio-demographic factors of households are included, such as the size of the household, household income, presence of children, race, and ethnicity of the household, and region (Pollak and Wales, 1981). The value of coupons are considered to examine the impact of coupons in the dairy promotion.

In the Nielsen Homescan Panel, the purchasing records are reported for each household over time, including expenditure in dollars, the coupon value in dollars, and the quantity purchased in ounces. The following steps have been done in order to obtain the panel data set. First, purchasing records for each household are aggregated for the same calendar year, thus 6 observations are available for each household, which includes the total expenditure per year, the total coupon values per year, and the total quantity per year for each dairy category for each household. Second, because Nielsen Homescan panel does not include prices, unit values[28] per year for each dairy category for each household are generated as proxies of the prices by dividing the total expenditure per year over the total quantity per year. Notice that there are no purchases for some aforementioned products for some years, so the total quantity per year is zero, which results in missing values of prices. To solve this censoring issue, we imputed prices for product i based on the following auxiliary specification (Alviola and Capps, 2010)

$$\log\left(Price_{i,obseved}\right) = a_0 + a_1 \log\,(Income) + a_2 \log\,(Household\ Size) + a_3 Region + u_i \qquad (6)$$

In Equation (15), the dependent variable is the observed unit values for product i. The independent variables include household income, household size, and region. Households with higher income levels are likely to pay higher prices since prices generally reflect the quality. Households with more members tend to purchase more bulk-packaged products, which are usually cheaper than the same products packaged in regular size. Region typically reflects the transportation costs and availability. Thus, we expect the parameters a_1 to be positive, a_2 to be negative, and a_3 to vary over nine regional delineations. The unit values for observed purchasing records and imputed unit values for missing records

[28] Unit values for each purchasing record are also calculated in order to detect the outliers. The records of quantity, total amount paid, and coupon values for the observations whose unit values that are out of the range of five standard deviations from the mean are deleted. At the same time, records are also deleted for observations with zero unit values. For these observations, households paid nothing for a certain amount of some products as buy one and get one free. (Rousseeuw and Hubert, 2011)

are used as the price variables in this study. In the end, the data set for this analysis includes annual quantity (ounces), annual unit values ($/ounce), annual total expenditure ($), and annual coupon values ($) for each household through 2010 to 2015, associated with the socio-demographic characteristics of each household, including the size of the household, household income, presence of children, race, and ethnicity of the household, and region.

Tables IV-2 and IV-3 show the continuous and binary variables used in the study. Tables IV-4 and IV-5 show the descriptive statistics of variables for the whole sample. First, low-fat milk is the most annually purchased dairy product on average over the period 2010 to 2015 by households at 2357.97 ounces per year. For the other fluid milk products, skim milk is the second at 2094.75 ounces per year, followed by whole milk (1278.69 oz/year), organic milk (1002.15 oz/year), and flavored milk (465.43 oz/year). The average quantity of plant-based milk alternatives is slightly larger than flavored milk at 544.69 ounces per year. The average quantity of butter is 146.63 ounces per year, which is smaller than margarine (182.39 oz/year). The average quantity of natural cheese is 328.01 ounces per year, which is more than twice of processed cheese (143.46 oz/year). The average quantity of Greek yogurt is 198.89 ounces per year, while for non-Greek yogurt, the average quantity is much larger at 416.06 ounces per year. The average quantity of ice cream is 457.83 ounce per year.

Second, the average expenditure on low-fat milk ($61.18/year) is the highest in the milk category, followed by organic milk ($53.89/year), skim milk ($50.91/year), and whole milk ($34.71/year), while plant-based milk alternatives ($25.54/year) and flavored milk ($16.85/year) are the lowest in the milk category. The average expenditure on butter

($28.22/year) is greater than the average expenditure on margarine ($17.26/year). The average expenditure on natural cheese ($84.64/year) is the highest among the whole dairy products, which is almost triple the average expenditure of processed cheese ($30.08/year). The average expenditures on non-Greek yogurt ($39.28) and Greek yogurt ($34.06/year) are quite similar. The average expenditure on ice cream is 27.93 dollars per year.

Third, skim milk and low-fat milk have the lowest average price at three cents per ounce, while the average price of organic milk is the highest at 6 cents per ounce in the milk category. Prices of whole milk, flavored milk, and plant-based milk alternatives are on the order four to five cents per ounces. Average butter prices (22 cents per ounce) are double average margarine prices (12 cents per ounce). Average natural cheese prices (30 cents per ounce) are slightly higher than average prices of processed cheese (23 cents per ounce). Greek yogurt prices on average (19 cents per ounce) are almost double non-Greek yogurt (11 cents per ounce).

Fourth, through the period 2010 to 2015, the records of using coupons by the 28,109 households showed that only 1% of these records used coupons when purchasing organic milk, with the associated average coupon value at $89.08 per year. At the same time, 15% of the records used coupons when purchasing low-fat milk with the associated coupon value at $222.68 per year. For flavored milk, whole milk, skim milk, and plant-based milk alternatives coupon uses varied from 4% to 8%, and the associated coupon values varied from $12.06/year to $217.08/year. Natural cheese has the highest percent of coupon uses at 38% with the associated coupon value at $365.92/year, followed by non-

Greek yogurt (28%, $263.4/year), processed cheese (24%, $141.53/year), ice cream(20%, $260.18/year), Greek yogurt (16%, $237.02/year), butter (19%, $183.22/year), and margarine (19%, $129.91/year).

Fifth, the age of household head, income, and household size are continuous variables. The average age of the household head is 56, the average household income is nearly $60,000, and the average household size is 2.18. In this analysis, the United States is divided into nine regions. The respective regions are (1) New England (the base as reference category); (2) Middle Atlantic; (3) East North Central; (4) West North Central; (5) South Atlantic; (6) East South Central; (7) West South Central; (8) Mountain; and (9) Pacific. For the race, 84% of the household heads are white (the base category), 9% are black, 3% are Asian, and 4% are other races, and 4% of the household heads are Hispanic. Slightly more than 80% of the household heads have at least a high school education, and 15% have children under 18 in the household.

Sixth, from Table IV-6, the imputed unit values and the observed unit values are very similar. However, the imputed unit values have a much lower variability. In this research, the unit values for observed purchase records and imputed prices for missing records are used as the price variable.

Model

Single-Equation Demand Model

Single-equation demand functions are estimated for each dairy product. The reduced form of the demand function is specified as follows,

$$y_{iht} = f(price_{iht}, price_{-iht}, housesiz_{ht}, income_{ht}, age_{ht}, edu_{ht}, region_{ht}, ethnicity_{ht}, children_{ht}, coupon\ value_{ht}) \quad (7)$$

Following Bellemare and Wichman 2020, we applied the inverse hyperbolic sine transformation to the purchases of dairy products. As such, the dependent variable is specified as follows,

$$y_{iht} = \log\,(Q_{iht} + \sqrt{Q_{iht}^2 + 1}) \quad (8)$$

where Q_{it} is the quantity of dairy product i purchased by household h in year t. Thus, the dependent variable equal to zero for the non-purchasing records, which makes it feasible for regression. The explanatory variables include the logarithm of own price of product i, the logarithm of prices of alternative dairy products[29], the logarithm of household size, the logarithm of income, the logarithm of the age of the household head, education status, region, race, ethnicity, presence of children, and coupon value.

[29] The alternative products selected vary depending on the specific dairy products. Specific alternatives and a weighted alternative category are included in the demand models for each dairy product. Details about the alternative products specification for each dairy category are delivered in Table IV-7.

Single equation demand models have some advantages when compared to the demand system models which are commonly used in previous studies.

(1) This research is conducted based on panel data which contains purchasing records of 28,109 households through the calendar year 2010 to 2015 from the Nielsen Homescan panel. As discussed before, a large number of zero observations occur for different dairy products which pose notable problems in the estimation of demand system models.

(2) With the demand system approach, restrictions such as the homogeneity condition, the adding–up condition, and the symmetry of the Slutsky matrix are imposed. But these restrictions often are not supported in the previous literature. (Heien and Wessells, 1988; Davis *et al.*, 2010; Davis *et al.*, 2011).

(3) The single-equation demand model is more flexible and faces less computational difficulties in estimation.

Empirical Results

SAS 9.4 is used for data organization, and R studio version 1.3.1073 is used to run the panel regressions for the demand models. In this section, the empirical results for Greek yogurt and plant-based milk alternatives are presented. The estimations for other dairy categories could be conducted based on the same methods. Table IV-8 shows the results of F tests for fixed time effects, BP tests for random time effects and random individual effects, as well as Hausman tests. The p-values of F tests and BP tests all are less than the 5% significant level, which means that fixed time effects, random time effects, and random individual effects exist in the data set. As such, pooled OLS is not appropriate. The P-values of the Hausman test are greater than the 5% significant level, indicating the two-way random effect models are favorable for both Greek yogurt and plant-based milk alternatives. Table IV-9 shows the empirical results for the demand functions for the two dairy products based on two-way random effect models. Table IV-10 exhibits the F test results for region and race, as well as adjusted R^2 for the demand models. The F-test results show that the region variables are jointly significant at the 5% level for both plant-based milk and Greek yogurt. The race variables are jointly significant at the 5% level for both plant-based milk and Greek yogurt. Table IV-11 shows the marginal effects of socio-demographic variables and elasticities for both plant-based milk and Greek yogurt.

Model 1 Plant-based Milk Alternatives

The significant variables include household size, household income level, age of household head, education level of household head, region, race, ethnicity, presence of children, price of plant-based milk alternatives, price of conventional milk, price of flavored milk, price of weighted alternative for plant-based milk products, and coupon value.

Households located in the Mountain, Pacific, West South Central, and South Atlantic regions purchase 26%, 23%, 2%, and 1% more plant-based milk alternatives compared to households located in the New England region respectively. Households located in other regions purchase less plant-based milk alternatives compared to households in the New England region, for example, , households located in the East South Central and the West North Central regions, purchase 9% and 7% less plant-based milk alternatives relative to households located in the New England region respectively.

White households purchase the least plant-based milk alternatives compared to all the other races. Asian households consume the most plant-based milk alternatives, which is 56 % more than white households. Black and other race households purchase more plant-based milk alternatives relative to white households, by 47% and 16% respectively. Hispanic households purchase 25% more plant-based milk alternatives than non-Hispanic households.

Households with children under 18 buy 11% less plant-based milk alternatives than households without children under 18. Households with at least high school education level buy 18% more plant-based milk alternatives than households with less than high school education.

The elasticity of demand of plant-based milk alternatives with respect to the age of household head is

-0.28. As the age of the household head increases, the quantity of plant-based milk alternatives declines.

The own-price elasticity of plant-based milk alternatives is -0.86. The cross-price elasticities of plant-based milk alternatives with respect to conventional milk and flavored milk are positive; as such these products are substitutes to plant-based milk alternatives. The cross-price elasticities of plant-based milk alternatives with respect to organic milk is negative which means that organic milk is complement to plant-based milk alternatives. The cross-price elasticity of plant-based milk alternatives with respect to the weighted alternative category of remaining dairy products also is positive, indicating that the products in other dairy categories are substitutes to plant-based milk alternatives. The income elasticity of plant-based milk alternatives is 0.08, indicating that plant-based milk alternatives is a necessity.

The elasticity of coupon value for plant-based milk alternatives is 0.51, which means that a 1% increase in coupon value would increase the purchase of plant-based milk alternatives by 0.51%, holding other factors constant.

Model 2 Greek Yogurt

The significant variables include household size, household income level, age of household head, education level of household head, region, race, ethnicity, presence of children, price of Greek yogurt, price of non-Greek yogurt, price of ice cream, price of conventional milk, price of weighted alternative for Greek yogurt, and coupon value.

Households located in the New England region purchase the most Greek yogurt compared to households located in other regions. Households in the East South Central, the West South Central regions, and the West North Central buy 48%, 44%, and 44% less than households located in the New England region respectively.

White households purchase the most Greek yogurt compared to all the other races. Black households buy the least Greek yogurt, which is 39% less than white households. Asian and other households buy less Greek yogurt than white households, by 16% and 1% respectively. Hispanic households purchase 1% more Greek yogurt compared to non-Hispanic households.

Households with children under 18 purchase 3% less Greek yogurt than households without children under 18. Households with at least high school education level purchase 37% more Greek yogurt than households with less than high school education.

The elasticity of demand for Greek yogurt with respect to the age of the household head is -0.19, which means that older household heads purchase less Greek yogurt than younger household head.

The own-price elasticity of Greek yogurt is -0.96. The cross-price elasticities of Greek yogurt with respect to non-Greek yogurt, conventional milk, ice cream are all positive, which means that these products are substitutes to Greek yogurt. The cross-price elasticity of Greek yogurt with respect to the weighted alternative category is negative, which means the products in other dairy categories are complements to Greek yogurt. The income elasticity of Greek yogurt is 0.25, indicating that Greek yogurt is a necessity.

The elasticity of coupon value for Greek yogurt is 0.29, which means that a 1% increase in coupon value would increase the purchase of Greek yogurt by 0.29%, holding other factors constant.

Concluding Remarks

This study intends to analyze the U.S. households purchasing behaviors of a granular array of dairy products and dairy alternative products. The demand of thirteen dairy categories are estimated based on a panel data set from Nielsen Homescan Panel for the calendar year 2010 to 2015 at the household level. Two-way random effects models are used to estimate price elasticities, income elasticities, and household socio-demographic marginal effects.

Households' socio-demographic characteristics play significant roles in affecting the demand for different dairy products and dairy alternative products. More wealthy households, younger households, households with higher education level, households with less children seem to purchase more plant-based milk alternatives and more Greek yogurt than households with contrary characteristics. Based on own-price elasticities, the demand of plant-based milk alternatives and Greek yogurt were almost unitary. Hence, pricing strategy might not be an effective way for retailors to increase revenue, holding other factors constant. Region, race, and coupon values also have significant effects on the demand for these two representative dairy categories.

Our research extended the demand analysis on the dairy complex, since most extant studies were conducted based on cross-sectional or time- series data, which usually contain incomprehensive information of the demand for different dairy products. At the same time, there are some limitations and directions could be focused on in the future study. First, our research is restricted to the data of the calendar year 2015. More recent data should be used to check on the robustness of the results. Second, while single equation models have advantages in flexibility and computation, they fail to capture the interrelationships among dairy demands systematically. Demand system, such as EASI model (Pendakur, 2009) might be used in future study. Last, in our study, the censoring issue for the demand of the dairy complex was neglected automatically because of the use of the inverse hyperbolic sine transformation. In the future study, we might consider using tobit [30] model associated with random effects to capture both the censoring issue and effects of omitted variables.

[30] The traditional tobit model, which was widely used in extant literatures, was also estimated in this study. The results from tobit model were similar as the results of the heterogeneous panel regression model.

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Table IV-1 Market Penetration for Different Dairy Products from 2007 to 2015

Year	White Milk	Flavored Milk	Butter	Ice Cream	Natural Cheese	Processed Cheese	Non-Greek Yogurt	Greek Yogurt	PMA[31]
2007	95%	28%	63%	86%	94%	90%	77%	0%	11%
2008	95%	27%	65%	77%	94%	90%	79%	2%	12%
2009	95%	28%	67%	76%	94%	90%	79%	5%	13%
2010	94%	28%	66%	75%	94%	90%	80%	20%	17%
2011	94%	26%	67%	72%	94%	89%	78%	35%	19%
2012	93%	25%	69%	71%	95%	89%	75%	44%	21%
2013	93%	23%	71%	72%	95%	88%	72%	53%	23%
2014	92%	21%	70%	72%	95%	87%	73%	54%	28%
2015	92%	23%	71%	71%	96%	86%	73%	54%	29%

Source: Nielsen Homescan panel, calendar years 2007 to 2015

[31] Short for plant-based milk alternatives

Table IV-2 Continuous Variables

Quantity	Price	Expenditure	Coupon Value ($)	Income	Household	Household Head Age
Flavored Milk	Flavored Milk	Flavored Milk	Flavored Milk	Household income corresponds to the use of midpoints of various intervals for each year from 2010 to 2015 from Nielsen Homescan data.	1-9+ Members	Household head age corresponds to the use of midpoints of various intervals for each year from 2010 to 2015 from Nielsen Homescan data.
Organic Milk	Organic Milk	Organic Milk	Organic Milk			
Skim Milk	Skim Milk	Skim Milk	Skim Milk			
Whole Milk	Whole Milk	Whole Milk	Whole Milk			
Low-fat Milk	Low-fat Milk	Low-fat Milk	Low-fat Milk			
PMA	PMA	PMA	PMA			
Butter	Butter	Butter	Butter			
Margarine	Margarine	Margarine	Margarine			
Ice Cream	Ice Cream	Ice Cream	Ice Cream			
Natural Cheese	Natural Cheese	Natural Cheese	Natural Cheese			
Processed Cheese	Processed Cheese	Processed Cheese	Processed Cheese			
Non-Greek Yogurt	Non-Greek Yogurt	Non-Greek Yogurt	Non-Greek Yogurt			
Greek Yogurt	Greek Yogurt	Greek Yogurt	Greek Yogurt			

Table IV-3 Binary Variables

<table>
<tr><th>Region</th><th>Race</th><th>Ethnicity</th><th>Education</th><th>Presence of Children</th><th>Coupon Use</th></tr>
<tr><td>New England</td><td rowspan="2">White/Caucasian</td><td rowspan="5">not Hispanic</td><td rowspan="5">Some High School or less</td><td rowspan="5">No Children Under 18</td><td rowspan="5">did not use coupon</td></tr>
<tr><td>Middle Atlantic</td></tr>
<tr><td>East North Central</td><td rowspan="3">Black/ African American</td></tr>
<tr><td>West North Central</td></tr>
<tr><td>South Atlantic</td></tr>
<tr><td>East South Central</td><td rowspan="2">Asian</td><td rowspan="4">Hispanic</td><td rowspan="4">Graduated High School or higher</td><td rowspan="4">Children under 18</td><td rowspan="4">used coupon</td></tr>
<tr><td>West South Central</td></tr>
<tr><td>Mountain</td><td rowspan="2">Other</td></tr>
<tr><td>Pacific</td></tr>
</table>

*Base or reference categories are in italics.

Table IV-4 Summary Statistics on Quantity, Expenditure, Price(Unit Value), Coupon Value, and Use of Coupon, Conditional on Purchase

Quantity (ounces)						
Products	**No. of Obs.**	**Mean**	**Std. Dev**	**Min**	**Max**	**Proportion of Obs.**
Flavored Milk	39,796	465.43	1012.35	7.00	18496.00	24%
Organic Milk	11,674	1002.15	1634.37	8.00	18496.00	7%
Skim Milk	54,868	2094.75	3003.52	8.00	67328.00	33%
Whole Milk	61,983	1278.69	2362.11	8.00	47872.00	37%
Low-fat Milk	124,188	2357.97	3045.20	8.00	43346.00	74%
PMA	34,787	544.69	925.42	8.00	15328.00	21%
Butter	119,598	146.63	171.59	2.00	4672.00	71%
Margarine	114,361	182.39	207.00	0.99	11610.00	68%
Ice Cream	123,526	457.83	636.09	5.80	20096.00	73%
Natural Cheese	160,009	328.01	359.00	0.70	6825.00	95%
Processed Cheese	148,604	143.46	153.32	0.84	4092.00	88%
Non-Greek Yogurt	125,765	416.06	561.02	3.49	14022.00	75%
Greek Yogurt	73,431	198.89	352.43	3.50	9533.70	44%
Expenditure ($)						
Products	**No. of Obs.**	**Mean**	**Std. Dev**	**Min**	**Max**	**Proportion of Obs.**
Flavored Milk	39,796	16.85	34.95	0.01	680.88	24%
Organic Milk	11,674	53.89	84.59	0.01	1126.77	7%
Skim Milk	54,868	50.91	69.55	0.00	1521.02	33%
Whole Milk	61,983	34.71	59.64	0.01	1397.75	37%
Low-fat Milk	124,188	61.18	74.39	0.00	1211.43	74%
PMA	34,787	25.54	42.97	0.02	693.72	21%
Butter	119,598	28.22	31.62	0.01	687.48	71%
Margarine	114,361	17.26	18.36	0.00	426.53	68%
Ice Cream	123,526	27.93	38.05	0.00	1540.19	73%
Natural Cheese	160,009	85.64	84.29	0.03	1357.49	95%
Processed Cheese	148,604	30.08	31.38	0.02	1226.22	88%
Non-Greek Yogurt	125,765	39.28	53.81	0.00	2120.73	75%
Greek Yogurt	73,431	34.06	61.35	0.00	1841.51	44%

Table IV-4 Continued

Price ($/ounce)					
Products	**No. of Observations**	**Mean**	**Std. Dev**	**Min**	**Max**
Flavored Milk	39,796	0.05	0.03	0.003	0.17
Organic Milk	11,674	0.06	0.01	0.007	0.22
Skim Milk	54,868	0.03	0.01	0.001	0.10
Whole Milk	61,983	0.04	0.02	0.005	0.12
Low-fat Milk	124,188	0.03	0.02	0.002	0.11
PMA	34,787	0.05	0.02	0.009	0.13
Butter	119,598	0.22	0.09	0.014	0.65
Margarine	114,361	0.12	0.06	0.003	0.43
Ice Cream	123,526	0.08	0.05	0.003	0.34
Natural Cheese	160,009	0.30	0.10	0.031	0.82
Processed Cheese	148,604	0.23	0.09	0.017	0.68
Non-Greek Yogurt	125,765	0.11	0.06	0.002	0.40
Greek Yogurt	73,431	0.19	0.08	0.003	0.57
Coupon Value ($)					
Products	**No. of Observations**	**Mean**	**Std. Dev**	**Min**	**Max**
Flavored Milk	39,796	0.55	2.68	0.00	144.31
Organic Milk	11,674	0.54	2.85	0.00	89.08
Skim Milk	54,868	1.17	4.78	0.00	217.08
Whole Milk	61,983	0.42	2.54	0.00	127.06
Low-fat Milk	124,188	1.08	4.74	0.00	222.68
PMA	34,787	1.69	4.94	0.00	115.35
Butter	119,598	0.93	2.95	0.00	183.22
Margarine	114,361	0.79	2.46	0.00	129.91
Ice Cream	123,526	1.31	4.53	0.00	260.18
Natural Cheese	160,009	2.65	7.82	0.00	365.92
Processed Cheese	148,604	0.90	2.81	0.00	141.53
Non-Greek Yogurt	125,765	2.11	6.75	0.00	263.40
Greek Yogurt	73,431	1.75	5.53	0.00	237.02

Table IV-4 Continued

Coupon Use (binary)		
Products	**No. of Observations**	**Mean**
Flavored Milk	7,252	0.04
Organic Milk	1,727	0.01
Skim Milk	11,101	0.07
Whole Milk	6,446	0.04
Low-fat Milk	24,549	0.15
Plant-based Milk Alternatives	12,890	0.08
Butter	32,293	0.19
Margarine	32,112	0.19
Ice Cream	33,054	0.20
Natural Cheese	64,070	0.38
Processed Cheese	40,139	0.24
Non-Greek Yogurt	46,537	0.28
Greek Yogurt	26,734	0.16

Table IV-5 Summary Statistics for the Respective Socio-demographic Variables

Variable	No. of Observations	Mean
New England	168,654	0.05
Middle Atlantic	168,654	0.13
East North Central	168,654	0.18
West North Central	168,654	0.09
South Atlantic	168,654	0.20
East South Central	168,654	0.06
West South Central	168,654	0.10
Mountain	168,654	0.07
Pacific	168,654	0.12
White	168,654	0.84
Black	168,654	0.09
Asian	168,654	0.03
Other	168,654	0.04
Ethnicity[32]	168,654	0.04
Education[33]	168,654	0.81
Presence of Children	168,654	0.15

[32] Reference category: non-Hispanic
[33] Reference category: Less than high school education

Table IV-5 Continued

Variable	No. of Observations	Mean	Std. Dev	Min	Max
Household Size	168,654	2.18	1.16	1	9
Household Head Age	168,654	56	11	22	65
Household Income($)	168,654	58,279	28,805	2,500	100,000

Table IV-6 Summary Statistics of Observed and Imputed Prices.

	Observed Price ($/ounce)		Imputed Price ($/ounce)	
Products	**No. of Observations**	**Mean**	**No. of Observations**	**Mean**
Flavored Milk	39,904	0.05	168,654	0.05
Organic Milk	11,663	0.06	168,654	0.06
Skim Milk	54,949	0.03	168,654	0.03
Whole Milk	62,104	0.04	168,654	0.03
Low-fat Milk	124,319	0.03	168,654	0.03
Plant-based Milk Alternatives	35,035	0.05	168,654	0.05
Butter	119,877	0.22	168,654	0.20
Margarine	114,711	0.12	168,654	0.10
Ice Cream	123,809	0.08	168,654	0.07
Natural Cheese	160,492	0.30	168,654	0.29
Processed Cheese	149,084	0.23	168,654	0.22
Non-Greek Yogurt	126,046	0.11	168,654	0.10
Greek Yogurt	73,682	0.19	168,654	0.18

Table IV-7 Alternative Specifications for the Respective Demand Model for Different Dairy Products.

	Specific Alternatives					**Weighted Alternative Category [34](WAC)**						
Flavored Milk	Conventional[35] White Milk	Organic Milk	PMA			Butter	Cheese	Yogurt	Ice Cream			
Organic Milk	Conventional White Milk	Flavored Milk	PMA			Butter	Cheese	Yogurt	Ice Cream			
Skim Milk	Low-fat Milk	Flavored Milk	Organic Milk	PMA	Whole Milk	Butter	Cheese	Yogurt	Ice Cream			
Whole Milk	Low-fat Milk	Flavored Milk	Organic Milk	PMA	Skim Milk	Butter	Cheese	Yogurt	Ice Cream			
Low-fat Milk	Whole Milk	Flavored Milk	Organic Milk	PMA	Skim Milk	Butter	Cheese	Yogurt	Ice Cream			
PMA	Conventional White Milk	Flavored Milk	Organic Milk			Butter	Cheese	Yogurt	Ice Cream			
Butter	Margarine					Yogurt	Cheese	PMA	Ice Cream	Organic Milk	Conventional White Milk	Flavored Milk
Margarine	Butter					Yogurt	Cheese	PMA	Ice Cream	Organic Milk	Conventional White Milk	Flavored Milk
Ice Cream	Non-Greek Yogurt	Greek Yogurt				Butter	Cheese	PMA	Ice Cream	Organic Milk	Conventional White Milk	Flavored Milk
Natural Cheese	Conventional White Milk	Processed Cheese				Butter	Cheese	Yogurt	Ice Cream	Organic Milk	PMA	Flavored Milk
Processed Cheese	Conventional White Milk	Natural Cheese				Butter	Cheese	Yogurt	Ice Cream	Organic Milk	PMA	Flavored Milk
Non-Greek Yogurt	Conventional White Milk	Greek Yogurt	Ice Cream			Butter	Cheese	PMA	Organic Milk	Flavored Milk		
Greek Yogurt	Conventional White Milk	Non-Greek Yogurt	Ice Cream			Butter	Cheese	PMA	Organic Milk	Flavored Milk		

[34] Represents categories used to calculate weighed average price of other dairy products, which is generated by the ratio between the summation of expenditure and the summation of the quantity of products included in this category. Missing records of the unit values for this category are imputed based on equation (6).

[35] Conventional milk includes skim milk, low-fat milk, and whole milk. The price of conventional milk, which is generated by the ratio between the summation of expenditure and the summation of the quantity of the three milk products included in this category, is used in the demand model to avoid potential collinearity problem. Similar situation for cheese (including both natural cheese and processed cheese) and yogurt (including both Greek and non-Greek yogurt) categories.

Table IV-8 Tests for Fixed Effects and Random Effects as well Hausman tests for Greek Yogurt and Plant-based Milk Alternatives

	F-test for fixed time effects	BP-test for random time effects	BP-test for random group effects	Hausman test (Mixed effects vs two-way random effects)
Products	p-value	p-value	p-value	p-value
PMA	**0.00**	**0.00**	**0.00**	**0.46**
Greek Yogurt	**0.00**	**0.00**	**0.00**	**1.00**

Note: numbers in bold are significant at the 5% significant level

Table IV-9 Empirical Results of the Respective Demand Models for Plant-based Milk Alternatives and Greek Yogurt

Plant-based Milk Alternatives			Greek Yogurt		
	Estimate	p-Value		Estimate	p-Value
Intercept	0.55	0.21	Intercept	**0.99**	**0.01**
log(household size)	**0.16**	**0.00**	log(household size)	**0.23**	**0.00**
log(income)	**0.08**	**0.00**	log(income)	**0.25**	**0.00**
log(age)	**-0.28**	**0.00**	log(age)	**-0.19**	**0.00**
Education	**0.16**	**0.00**	Education	**0.31**	**0.00**
Middle Atlantic	0.00	0.93	Middle Atlantic	**-0.17**	**0.00**
East North Central	-0.03	0.54	East North Central	**-0.43**	**0.00**
West North Central	-0.07	0.22	West North Central	**-0.57**	**0.00**
South Atlantic	0.01	0.82	South Atlantic	**-0.37**	**0.00**
East South Central	-0.10	0.14	East South Central	**-0.63**	**0.00**
West South Central	0.01	0.80	West South Central	**-0.57**	**0.00**
Mountain	**0.23**	**0.00**	Mountain	**-0.33**	**0.00**
Pacific	**0.21**	**0.00**	Pacific	**-0.42**	**0.00**
Black/ African American	**0.38**	**0.00**	Black/ African American	**-0.48**	**0.00**
Asian	**0.44**	**0.00**	Asian	**-0.17**	**0.00**
Other	**0.15**	**0.00**	Other	**-0.10**	**0.02**
Hispanic	**0.22**	**0.00**	Hispanic	**0.10**	**0.03**
Presence of Children	**-0.12**	**0.00**	Presence of Children	-0.03	0.20
log(Price of PMA)	**-0.85**	**0.00**	log(Price of Greek Yogurt)	**-0.94**	**0.00**
log(Price of Conventional Milk)	**0.37**	**0.00**	log(Price of non-Greek Yogurt)	**0.52**	**0.00**
log(Price of Organic Milk)	-0.01	0.93	log(Price of Ice Cream)	**0.22**	**0.00**
log(Price of Flavored Milk)	**0.09**	**0.00**	log(Price of Conventional Milk)	**0.19**	**0.00**
log(Price of WAC for PMA)	**0.19**	**0.00**	log(Price of WAC for Greek Yogurt)	-0.01	0.36
Coupon Value for PMA	**0.30**	**0.00**	Coupon Value for Greek Yogurt	**0.16**	**0.00**
	variance	share		variance	share
Time effects	0.02	0.00	Time effects	0.37	0.06
Individual effects	2.79	0.50	Individual effects	2.71	0.44
iid error	2.85	0.50	iid error	3.11	0.50

Table IV-10 F- tests for Region and Race, R^2 of Demand Functions for Different Dairy Products

	F-test for region		F-test for race		adj. R^2
	F- Statistic	P-value	F- Statistic	P-value	
PMA	**19.32**	**0.00**	**89.27**	**0.00**	0.09
Greek Yogurt	**32.35**	**0.00**	**57.48**	**0.00**	0.09

Table IV-11 Marginal Effects and Elasticities Associated with the Demand Model for Plant-based Milk Alternatives and Greek Yogurt

Plant-based Milk Alternatives		Greek Yogurt	
Elasticity[36]		***Elasticity***	
Household size	0.16	Household size	0.24
Income	0.08	Income	0.25
Age	-0.28	Age	-0.19
Price of PMA	-0.86	Price of Greek Yogurt	-0.96
Price of Conventional Milk	0.38	Price of non-Greek Yogurt	0.53
Price of Organic Milk	-0.01	Price of Ice Cream	0.23
Price of Flavored Milk	0.09	Price of Conventional Milk	0.19
Price of WAC for PMA	0.19	Price of WAC for Greek Yogurt	-0.01
Coupon Value for PMA[37]	0.51	Coupon Value for Greek Yogurt	0.29
Marginal Effect[38]		***Marginal Effect***	
Education	0.18	Education	0.37
Middle Atlantic	0.00	Middle Atlantic	-0.16
East North Central	-0.03	East North Central	-0.36
West North Central	-0.07	West North Central	-0.44
South Atlantic	0.01	South Atlantic	-0.32
East South Central	-0.09	East South Central	-0.48
West South Central	0.02	West South Central	-0.44
Mountain	0.26	Mountain	-0.29
Pacific	0.23	Pacific	-0.35
Black/ African American	0.47	Black/ African American	-0.39
Asian	0.56	Asian	-0.16
Other	0.16	Other	-0.10
Hispanic	0.25	Hispanic	0.10
Presence of Children	-0.11	Presence of Children	-0.03

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[36] The elasticity is calculated as follows: $\varepsilon = \frac{dlog(Q)}{dlog(P)} = \frac{\sqrt{q^2+1}}{q} * \beta$, where q is the conditional mean of the quantity and β is the parameter estimated from the demand model.

[37] The elasticity for coupon value is calculated as follows: $\varepsilon = \frac{dlog(Q)}{dlog(CV)} = \frac{\sqrt{q^2+1}}{q} * \beta * CV$, where q is the conditional mean of the quantity, β is the parameter estimated from the demand model, and CV is the conditional mean of the coupon value.

[38] The marginal effects is calculated as follows: $b = e^a - 1$, where $a = \frac{dlog(Q)}{dx} = \frac{\sqrt{q^2+1}}{q} * \beta$, q is the conditional mean of the quantity and β is the parameter estimated from the demand model.

CHAPTER V

SUMMARY AND CONCLUSION

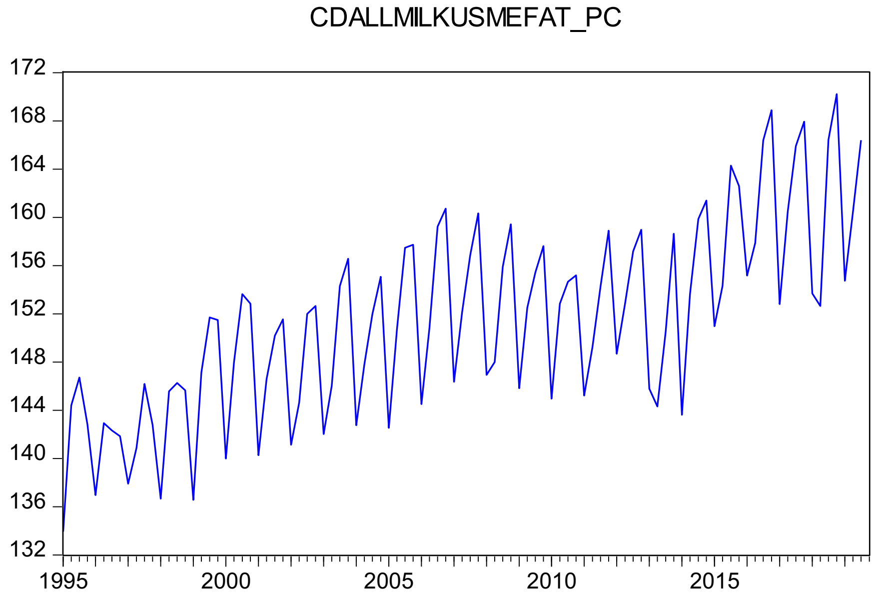
The changes in the demand for dairy products in recent decades have been a major concern to stakeholders in the dairy industry. A wider array of dairy products and more dairy alternative products have been offered to US consumers. This study intends to analyze the U.S. households purchasing behaviors of a granular array of dairy products and dairy alternative products. Three different data sets from Nielsen Homescan panel were used to estimate the long run and short run demands for different dairy products.

In the first paper, we used a cross-sectional data set containing households purchasing records of thirteen dairy and dairy alternative products for calendar year 2015 to estimate the long-run price and income elasticities, as well as household socio-demographic characteristic effects for different dairy and dairy alternative products. Because of zero purchases, the Heckman two-step procedure is used to deal with the censoring problem. Take two representative products, Greek yogurt and plant-based milk alternatives, for examples, the own-price elasticities of both products are found to be elastic and close to unitary. The income elasticities of both products are positive and below unity. Socio-demographic characteristics have significant impacts on the demand of different dairy products and dairy alternative products. Households with higher income level, no children under 18, younger household heads, college educated household heads purchased more quantity of Greek yogurt and plant based milk alternatives. This study based on single-equation demand models, which is flexible and faces few computational difficulties, could be used as a baseline of dairy market analysis for stakeholders. However, this method failed to capture the interrelationships among different dairy demands systematically. Thus in the second paper, we conducted demand system analyses to deal with this problem.

In the second paper, the QUAIDS and the Barten's synthetic model have been utilized to investigate the demand for nine dairy products and dairy alternative products based on monthly time-series data through January 2010 to November 2015 from Nielsen Homescan Panel data. Issues such as serial correlation, endogeneity of total expenditure, and seasonality were addressed during the estimation. The uncompensated and compensated price elasticities as well as the expenditure elasticities, are estimated from this research. The uncompensated and compensated own-price elasticities for plant-based milk alternatives and Greek yogurt were found to be elastic. Both models indicated Greek yogurt to be necessities, while for plant-based milk alternatives, QUAIDS indicated it to be luxury and Barten model suggest it to be necessity. These findings provide useful information for retailers to develop pricing strategies to maximize the revenue at least in the short run. As to the future studies concerning this essay, we need to determine which model is more suitable for this dataset, since these two models indicated different results for some elasticities. Another limitation is that this study is conducted based on time-series data at the aggregated over household level. The time-series data allows us to analyze the demand change over different periods, captures the short-term impacts of price on quantity, and facilitate computation. However, it fails to capture the socio-demographic characteristics of households. This problem could be overcome by a panel data analysis. A panel data analysis could provide more accurate inference of the model parameters, control heterogeneity of cross-section units over time, and mitigate the impact of the omitted variables.

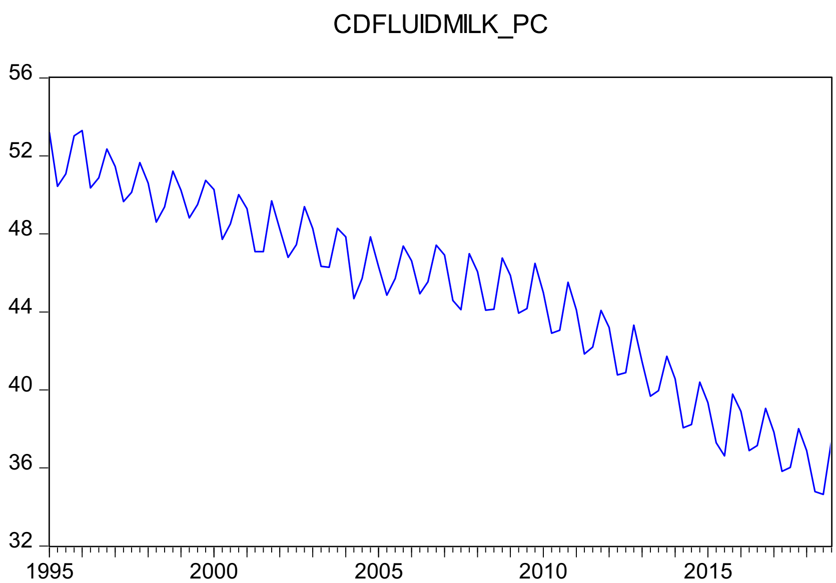
In the third paper, we estimated the demand of the same thirteen dairy categories as in the first paper based on a panel data set from Nielsen Homescan Panel for the calendar year 2010 to 2015 at the household level. Two-way random effects models are used to estimate price elasticities, income elasticities, and household socio-demographic marginal effects. Results show that households' socio-demographic characteristics play significant roles in affecting the demand for different dairy products and dairy alternative products. Households with higher income level, no children under 18, younger household heads, college educated household heads purchased more quantities of Greek yogurt and plant based milk alternatives than households with contrary characteristics. Based on own-price elasticities, the demand of plant-based milk alternatives and Greek yogurt were inelastic but close to unitary. Hence, pricing strategy might not be an effective way for retailors to increase revenue, holding other factors constant. Region, race, and coupon values also have significant effects on the demand for these two representative dairy categories. This study provided a robustness check to the cross-sectional analysis. According to the results, the marginal effects of household socio-demographic characteristics indicated the same profile of target customers for both representative products. The panel data analysis revealed inelastic own-price elasticities for both products while the cross-sectional analysis indicated elastic own-price elasticities for the demand of both products in calendar year 2015, though the own-price elasticities from both studies were found to be close to unitary. This difference could be explained by many reasons, such as the difference between sample means of the two data sets, more information involved in the panel data set, the censoring problem of the data sets, and so on. A major concern might be that in our study, the censoring issue for the demand of the dairy complex was neglected automatically because of the use of the inverse hyperbolic sine transformation. In the future study, we might consider using tobit model associated with random effects to capture both the censoring issue and effects of omitted variables.

Figure 1 Quarterly Per Capita U.S. Consumption of All Dairy Products on a Milk Fat Basis, 1995 to 2018 (in pounds)



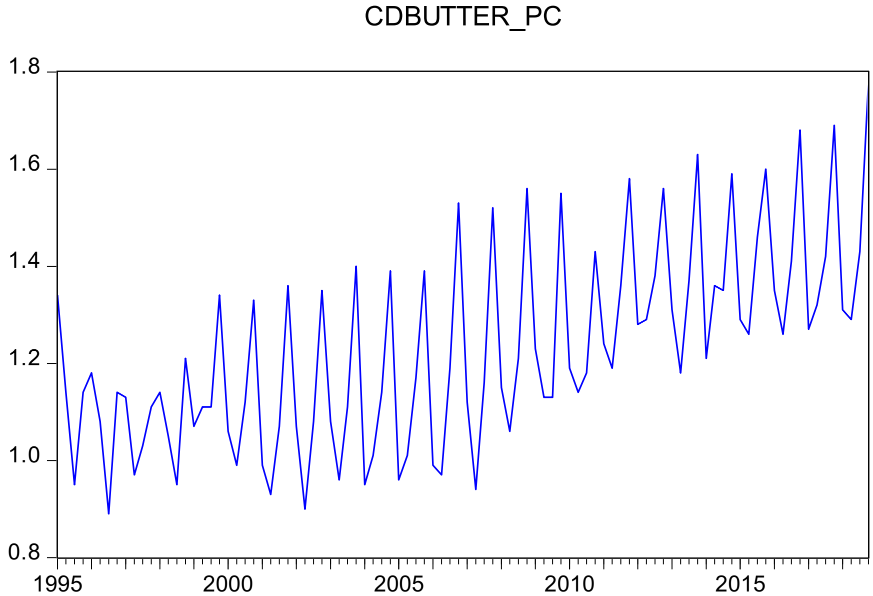
Source: U.S. Department of Agriculture

Figure 2 Quarterly Per Capita U.S. Consumption of Fluid Milk, 1995 to 2018 (in pounds)



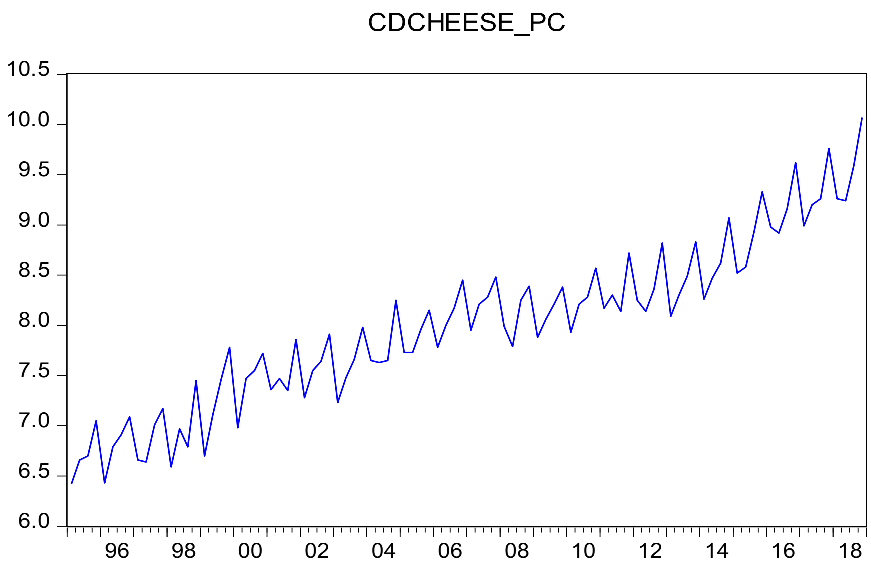
Source: U.S. Department of Agriculture

Figure 3 Quarterly Per Capita U.S. Consumption of Butter, 1995 to 2018 (in pounds)



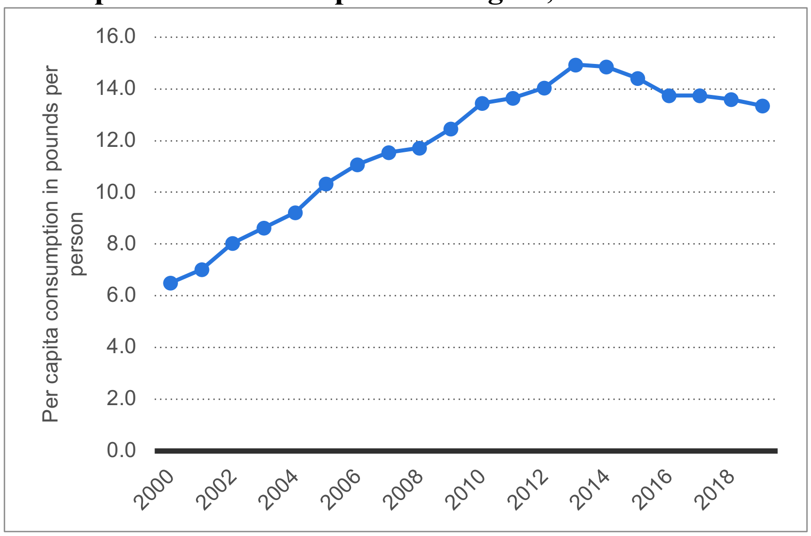
Source: U.S. Department of Agriculture

Figure 4 Quarterly Per Capita U.S. Consumption of Cheese, 1995 to 2018 (in pounds)



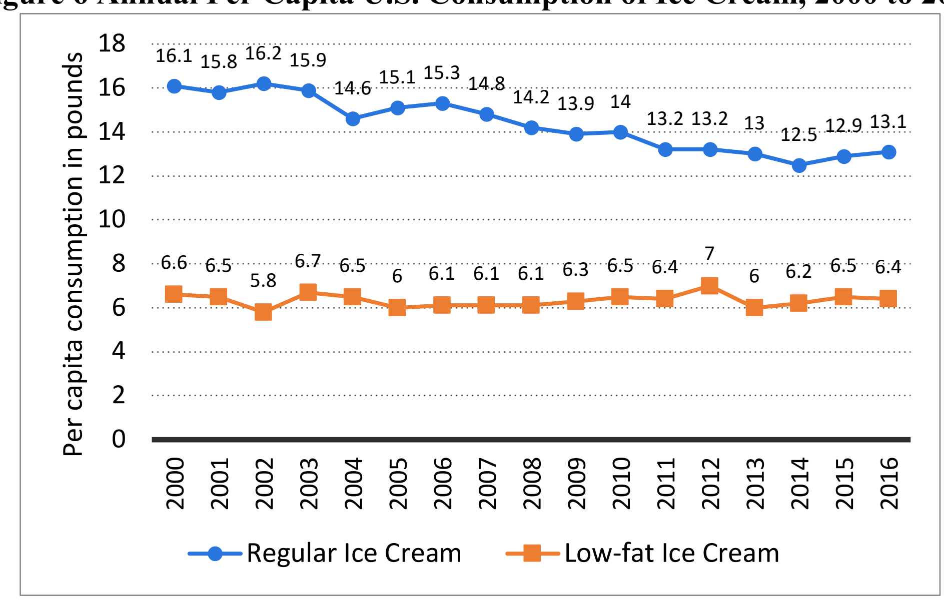
Source: U.S. Department of Agriculture

Figure 5 Per Capita U.S. Consumption of Yogurt, 2000 to 2019



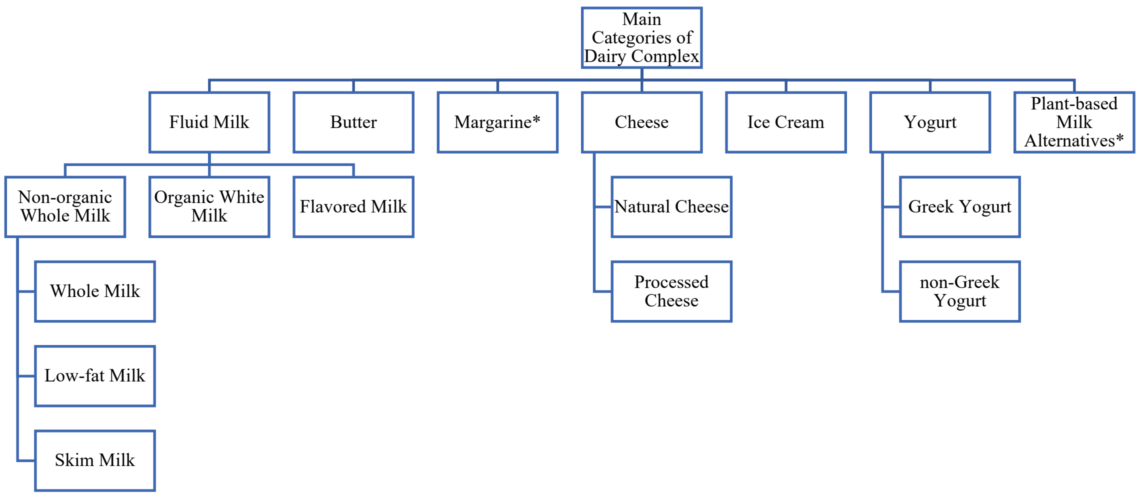
Source: U.S. Department of Agriculture

Figure 6 Annual Per Capita U.S. Consumption of Ice Cream, 2000 to 2016



Source: Statista; U.S. Department of Agriculture; Economic Research Service

Figure 7 Flow Chart for the Thirteen Dairy and Dairy Alternatives Products to be Analyzed



Note: margarine and plant-based milk alternatives are not dairy products.

APPENDIX A

Appendix A.1 Regional Delineation

Region	**States**
New England	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
Middle Atlantic	New Jersey, New York, Pennsylvania
East North Central	Indiana, Illinois, Michigan, Ohio, Wisconsin
West North Central	Iowa, Nebraska, Kansas, North Dakota,
South Atlantic	Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia
East South Central	Alabama, Kentucky, Mississippi, Tennessee
West South Central	Arkansas, Louisiana, Oklahoma, Texas
Mountain	Arizona, Colorado, Idaho, New Mexico, Montana, Utah, Nevada, Wyoming
Pacific	Alaska, California, Hawaii, Oregon, Washington

Appendix A.2 Empirical Results of Imputed Model for Price

Conventional White Milk			Flavored Milk			Skim Milk			Whole Milk		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**-3.67**	**0.00**	Intercept	**-2.95**	**0.00**	Intercept	**-3.47**	**0.00**	Intercept	**-3.88**	**0.00**
log(household size)	**-0.15**	**0.00**	log(household size)	**-0.09**	**0.00**	log(household size)	**-0.11**	**0.00**	log(household size)	**-0.16**	**0.00**
log(income)	**0.03**	**0.00**	log(income)	0.01	0.14	log(income)	**0.01**	**0.03**	log(income)	**0.06**	**0.00**
Middle Atlantic	0.00	0.51	Middle Atlantic	**-0.13**	**0.00**	Middle Atlantic	0.00	0.82	Middle Atlantic	0.00	0.76
East North Central	**-0.27**	**0.00**	East North Central	**-0.34**	**0.00**	East North Central	**-0.33**	**0.00**	East North Central	**-0.26**	**0.00**
West North Central	**-0.13**	**0.00**	West North Central	**-0.25**	**0.00**	West North Central	**-0.20**	**0.00**	West North Central	**-0.07**	**0.00**
South Atlantic	0.00	0.83	South Atlantic	**-0.10**	**0.00**	South Atlantic	**-0.03**	**0.03**	**South Atlantic**	**-0.02**	**0.09**
East South Central	**-0.12**	**0.00**	East South Central	**-0.19**	**0.00**	East South Central	**-0.20**	**0.00**	East South Central	**-0.09**	**0.00**
West South Central	**-0.10**	**0.00**	West South Central	**-0.10**	**0.00**	West South Central	**-0.15**	**0.00**	West South Central	**-0.11**	**0.00**
Mountain	**-0.32**	**0.00**	Mountain	**-0.25**	**0.00**	Mountain	**-0.35**	**0.00**	Mountain	**-0.29**	**0.00**
Pacific	**-0.05**	**0.00**	Pacific	**-0.09**	**0.00**	Pacific	**-0.15**	**0.00**	Pacific	**-0.05**	**0.00**
R^2	0.16		R^2	0.05		R^2	0.14		R^2	0.11	

Appendix A.2 Continued

Low-fat Milk			Plant-based Milk Alternatives			Organic Milk			Ice Cream		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**-3.74**	**0.00**	Intercept	**-3.03**	**0.00**	Intercept	**-3.67**	**0.00**	Intercept	**-3.58**	**0.00**
log(household size)	**-0.16**	**0.00**	log(household size)	**-0.02**	**0.00**	log(household size)	**-0.15**	**0.00**	log(household size)	**-0.15**	**0.00**
log(income)	**0.04**	**0.00**	log(income)	**0.01**	**0.00**	log(income)	**0.03**	**0.00**	log(income)	**0.12**	**0.00**
Middle Atlantic	0.00	0.81	Middle Atlantic	**0.05**	**0.00**	Middle Atlantic	0.00	0.51	Middle Atlantic	**-0.03**	**0.04**
East North Central	**-0.24**	**0.00**	East North Central	-0.01	0.34	East North Central	**-0.27**	**0.00**	East North Central	**-0.23**	**0.00**
West North Central	**-0.10**	**0.00**	West North Central	0.00	0.70	West North Central	**-0.13**	**0.00**	West North Central	**-0.31**	**0.00**
South Atlantic	0.01	0.36	South Atlantic	**-0.05**	**0.00**	South Atlantic	0.00	0.83	South Atlantic	**-0.13**	**0.00**
East South Central	**-0.13**	**0.00**	East South Central	**-0.06**	**0.00**	East South Central	**-0.12**	**0.00**	East South Central	**-0.25**	**0.00**
West South Central	**-0.11**	**0.00**	West South Central	**-0.04**	**0.00**	West South Central	**-0.10**	**0.00**	West South Central	**-0.11**	**0.00**
Mountain	**-0.32**	**0.00**	Mountain	**-0.06**	**0.00**	Mountain	**-0.32**	**0.00**	Mountain	**-0.18**	**0.00**
Pacific	**-0.03**	**0.00**	Pacific	-0.01	0.15	Pacific	**-0.05**	**0.00**	Pacific	**-0.05**	**0.00**
R^2	0.14		R^2	0.02		R^2	0.16		R^2	0.06	

Appendix A.2 Continued

Butter			Margarine			Cheese			Natural Cheese		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**-1.93**	**0.00**	Intercept	**-3.46**	**0.00**	Intercept	**-1.83**	**0.00**	Intercept	**-1.65**	**0.00**
log(household size)	**-0.02**	**0.00**	log(household size)	**-0.17**	**0.00**	log(household size)	**-0.05**	**0.00**	log(household size)	**-0.04**	**0.00**
log(income)	**0.04**	**0.00**	log(income)	**0.14**	**0.00**	log(income)	**0.04**	**0.00**	log(income)	**0.03**	**0.00**
Middle Atlantic	**0.05**	**0.00**	Middle Atlantic	**-0.08**	**0.00**	Middle Atlantic	**0.03**	**0.00**	Middle Atlantic	**0.04**	**0.00**
East North Central	0.01	0.38	East North Central	**-0.24**	**0.00**	East North Central	**0.07**	**0.00**	East North Central	**0.11**	**0.00**
West North Central	-0.01	0.31	West North Central	**-0.27**	**0.00**	West North Central	**0.09**	**0.00**	West North Central	**0.14**	**0.00**
South Atlantic	**0.04**	**0.00**	South Atlantic	**-0.15**	**0.00**	South Atlantic	**0.14**	**0.00**	South Atlantic	**0.19**	**0.00**
East South Central	-0.01	0.59	East South Central	**-0.30**	**0.00**	East South Central	**0.11**	**0.00**	East South Central	**0.18**	**0.00**
West South Central	0.01	0.13	West South Central	**-0.26**	**0.00**	West South Central	**0.08**	**0.00**	West South Central	**0.13**	**0.00**
Mountain	**0.07**	**0.00**	Mountain	**-0.14**	**0.00**	Mountain	**0.08**	**0.00**	Mountain	**0.10**	**0.00**
Pacific	**0.17**	**0.00**	Pacific	**-0.11**	**0.00**	Pacific	**0.11**	**0.00**	Pacific	**0.12**	**0.00**
R^2	0.04		R^2	0.07		R^2	0.03		R^2	0.03	

Appendix A.2 Continued

Processed Cheese			non-Greek Yogurt			Greek Yogurt			Yogurt		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**-1.95**	**0.00**	Intercept	**-2.63**	**0.00**	Intercept	**-1.68**	**0.00**	Intercept	**-2.66**	**0.00**
log(household size)	**-0.06**	**0.00**	log(household size)	**-0.01**	**0.00**	log(household size)	**-0.01**	**0.00**	log(household size)	**-0.05**	**0.00**
log(income)	**0.06**	**0.00**	log(income)	**0.04**	**0.00**	log(income)	0.00	0.70	log(income)	**0.06**	**0.00**
Middle Atlantic	**-0.02**	**0.01**	Middle Atlantic	0.00	1.00	Middle Atlantic	**0.02**	**0.00**	Middle Atlantic	0.00	0.82
East North Central	**-0.08**	**0.00**	East North Central	**-0.07**	**0.00**	East North Central	0.00	0.98	East North Central	**-0.08**	**0.00**
West North Central	**-0.09**	**0.00**	West North Central	**-0.08**	**0.00**	West North Central	**-0.01**	**0.05**	West North Central	**-0.09**	**0.00**
South Atlantic	-0.01	0.07	South Atlantic	**-0.02**	**0.03**	South Atlantic	0.01	0.06	South Atlantic	**-0.03**	**0.00**
East South Central	**-0.09**	**0.00**	East South Central	**-0.06**	**0.00**	East South Central	-0.01	0.30	East South Central	**-0.08**	**0.00**
West South Central	**-0.10**	**0.00**	West South Central	**-0.06**	**0.00**	West South Central	**-0.01**	**0.02**	West South Central	**-0.07**	**0.00**
Mountain	**-0.04**	**0.00**	Mountain	**-0.07**	**0.00**	Mountain	**-0.02**	**0.00**	Mountain	**-0.09**	**0.00**
Pacific	-0.01	0.35	Pacific	**-0.02**	**0.01**	Pacific	**-0.05**	**0.00**	Pacific	**-0.05**	**0.00**
R^2	0.04		R^2	0.01		R^2	0.01		R^2	0.03	

Appendix A.2 Continued

Alternative of Plant-based Milk Alternatives			Alternative of Organic Milk			Alternative of Butter			Alternative of Margarine		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**-2.50**	**0.00**	Intercept	**-2.50**	**0.00**	Intercept	**-3.45**	**0.00**	Intercept	**-3.45**	**0.00**
log(household size)	**-0.04**	**0.00**	log(household size)	**-0.04**	**0.00**	log(household size)	**-0.19**	**0.00**	log(household size)	**-0.19**	**0.00**
log(income)	**0.08**	**0.00**	log(income)	**0.08**	**0.00**	log(income)	**0.10**	**0.00**	log(income)	**0.10**	**0.00**
Middle Atlantic	**0.02**	**0.00**	Middle Atlantic	**0.02**	**0.00**	Middle Atlantic	**0.02**	**0.04**	Middle Atlantic	**0.02**	**0.04**
East North Central	**-0.03**	**0.00**	East North Central	**-0.03**	**0.00**	East North Central	**-0.17**	**0.00**	East North Central	**-0.17**	**0.00**
West North Central	**-0.05**	**0.00**	West North Central	**-0.05**	**0.00**	West North Central	**-0.13**	**0.00**	West North Central	**-0.13**	**0.00**
South Atlantic	**0.03**	**0.00**	South Atlantic	**0.03**	**0.00**	South Atlantic	0.02	0.07	South Atlantic	0.02	0.07
East South Central	**-0.03**	**0.00**	East South Central	**-0.03**	**0.00**	East South Central	**-0.12**	**0.00**	East South Central	**-0.12**	**0.00**
West South Central	**-0.02**	**0.00**	West South Central	**-0.02**	**0.00**	West South Central	**-0.06**	**0.00**	West South Central	**-0.06**	**0.00**
Mountain	-0.01	0.08	Mountain	-0.01	0.08	Mountain	**-0.11**	**0.00**	Mountain	**-0.11**	**0.00**
Pacific	**0.03**	**0.00**	Pacific	**0.03**	**0.00**	Pacific	**0.02**	**0.04**	Pacific	**0.02**	**0.04**
R^2	0.03		R^2	0.03		R^2	0.06		R^2	0.06	

Appendix A.2 Continued

Alternative of Ice Cream			Alternative of Natural Cheese			Alternative of Processed Cheese			Alternative of non-Greek Yogurt			Alternative of Greek Yogurt		
	Estimate	p-Value		Estimate	p-Value		Estimate	p-Value		Estimate	p-Value		Estimate	p-Value
Intercept	**-3.33**	**0.00**	Intercept	**-3.11**	**0.00**	Intercept	**-3.11**	**0.00**	Intercept	**-1.83**	**0.00**	Intercept	**-1.83**	**0.00**
log(household size)	**-0.23**	**0.00**	log(household size)	**-0.10**	**0.00**	log(household size)	**-0.10**	**0.00**	log(household size)	**-0.05**	**0.00**	log(household size)	**-0.05**	**0.00**
log(income)	**0.09**	**0.00**	log(income)	**0.10**	**0.00**	log(income)	**0.10**	**0.00**	log(income)	**0.02**	**0.00**	log(income)	**0.02**	**0.00**
Middle Atlantic	**0.04**	**0.00**	Middle Atlantic	-0.01	0.16	Middle Atlantic	-0.01	0.16	Middle Atlantic	0.01	0.24	Middle Atlantic	0.01	0.24
East North Central	**-0.15**	**0.00**	East North Central	**-0.19**	**0.00**	East North Central	**-0.19**	**0.00**	East North Central	0.01	0.18	East North Central	0.01	0.18
West North Central	**-0.09**	**0.00**	West North Central	**-0.21**	**0.00**	West North Central	**-0.21**	**0.00**	West North Central	**0.04**	**0.00**	West North Central	**0.04**	**0.00**
South Atlantic	**0.05**	**0.00**	South Atlantic	**-0.13**	**0.00**	South Atlantic	**-0.13**	**0.00**	South Atlantic	**0.08**	**0.00**	South Atlantic	**0.08**	**0.00**
East South Central	**-0.10**	**0.00**	East South Central	**-0.25**	**0.00**	East South Central	**-0.25**	**0.00**	East South Central	**0.05**	**0.00**	East South Central	**0.05**	**0.00**
West South Central	**-0.04**	**0.00**	West South Central	**-0.17**	**0.00**	West South Central	**-0.17**	**0.00**	West South Central	**0.02**	**0.01**	West South Central	**0.02**	**0.01**
Mountain	**-0.09**	**0.00**	Mountain	**-0.15**	**0.00**	Mountain	**-0.15**	**0.00**	Mountain	**0.03**	**0.00**	Mountain	**0.03**	**0.00**
Pacific	**0.06**	**0.00**	Pacific	**-0.07**	**0.00**	Pacific	**-0.07**	**0.00**	Pacific	**0.06**	**0.00**	Pacific	**0.06**	**0.00**
R^2	0.05		R^2	0.06		R^2	0.06		R^2	0.01		R^2	0.01	

Appendix A.3 Marginal Effects of the Explanatory Variables in the Respective Probit Models

Plant-based Milk Alternatives	marginal effect	Flavored Milk	marginal effect	Organic Milk	marginal effect
log(household size)	0.047	log(household size)	0.111	log(household size)	0.005
log(income)	0.000	log(income)	-0.001	log(income)	0.003
log(age)	-0.011	log(age)	-0.016	log(age)	-0.013
Education	0.028	Education	-0.034	Education	0.041
Middle Atlantic	-0.021	Middle Atlantic	0.034	Middle Atlantic	0.016
East North Central	-0.021	East North Central	0.122	East North Central	0.012
West North Central	-0.031	West North Central	0.146	West North Central	-0.016
South Atlantic	-0.019	South Atlantic	0.041	South Atlantic	0.012
East South Central	-0.023	East South Central	0.108	East South Central	0.011
West South Central	-0.019	West South Central	0.082	West South Central	0.044
Mountain	0.026	Mountain	0.063	Mountain	0.054
Pacific	0.005	Pacific	0.001	Pacific	0.038
Black/ African American	0.038	Black/ African American	-0.071	Black/ African American	-0.034
Asian	0.015	Asian	-0.067	Asian	0.047
Other	0.019	Other	-0.013	Other	0.008
Hispanic	0.014	Hispanic	-0.021	Hispanic	0.007
Presence of Children	-0.014	Presence of Children	0.022	Presence of Children	0.030
log(Price of PMA)	0.893	log(Price of Flavored Milk)	0.568	log(Price of Organic Milk)	-0.385
log(Price of Conventional	1.890	log(Price of PMA)	0.456	log(Price of Flavored Milk)	0.953
log(Price of Organic Milk)	0.292	log(Price of Conventional Milk)	-0.636	log(Price of Conventional Milk)	2.633
log(Price of Flavored Milk)	0.430	log(Price of Organic Milk)	0.337	log(Price of PMA)	0.233
log(Price of WAC for PMA)	0.202	log(Price of WAC for Flavored	-0.181	log(Price of WAC for Organic	0.305
Coupon Use for PMA	1.685	Coupon Use for Flavored Milk	1.414	Coupon Use for Organic Milk	1.479

Appendix A.3 Continued

Ice Cream	marginal effect	Natural Cheese	marginal effect	Processed Cheese	marginal effect
log(household size)	0.134	log(household size)	0.059	log(household size)	0.144
log(income)	-0.002	log(income)	0.000	log(income)	0.000
log(age)	0.011	log(age)	-0.003	log(age)	0.005
Education	-0.018	Education	-0.001	Education	-0.026
Middle Atlantic	-0.025	Middle Atlantic	-0.006	Middle Atlantic	-0.007
East North Central	0.025	East North Central	0.004	East North Central	0.021
West North Central	0.025	West North Central	0.005	West North Central	0.039
South Atlantic	0.019	South Atlantic	0.001	South Atlantic	0.013
East South Central	0.045	East South Central	-0.003	East South Central	0.045
West South Central	0.047	West South Central	-0.004	West South Central	0.018
Mountain	0.022	Mountain	0.008	Mountain	-0.006
Pacific	0.001	Pacific	-0.002	Pacific	-0.036
Black/ African American	-0.035	Black/ African American	-0.023	Black/ African American	-0.064
Asian	-0.085	Asian	-0.055	Asian	-0.098
Other	-0.014	Other	-0.005	Other	-0.025
Hispanic	-0.023	Hispanic	-0.003	Hispanic	-0.015
Presence of Children	-0.010	Presence of Children	-0.007	Presence of Children	-0.020
log(Price of Ice Cream)	-0.001	log(Price of Natural Cheese)	-0.011	log(Price of Processed Cheese)	0.035
log(Price of Greek Yogurt)	0.062	log(Price of Processed Cheese)	0.010	log(Price of Natural Cheese)	-0.004
log(Price of non-Greek	-0.197	log(Price of Conventional Milk)	-0.134	log(Price of Conventional Milk)	-0.775
log(Price of WAC for Ice	-0.394	log(Price of WAC for Natural	0.106	log(Price of WAC for Processed	-0.021
Coupon Use for Ice Cream	2.500	Coupon Use for Natural Cheese	0.362	Coupon Use for Processed Cheese	1.189

Appendix A.3 Continued

Low-fat Milk	marginal effect	Skim Milk	marginal effect	Whole Milk	marginal effect
log(household size)	0.134	log(household size)	0.059	log(household size)	0.144
log(income)	-0.002	log(income)	0.000	log(income)	0.000
log(age)	0.011	log(age)	-0.003	log(age)	0.005
Education	-0.018	Education	-0.001	Education	-0.026
Middle Atlantic	-0.025	Middle Atlantic	-0.006	Middle Atlantic	-0.007
East North Central	0.025	East North Central	0.004	East North Central	0.021
West North Central	0.025	West North Central	0.005	West North Central	0.039
South Atlantic	0.019	South Atlantic	0.001	South Atlantic	0.013
East South Central	0.045	East South Central	-0.003	East South Central	0.045
West South Central	0.047	West South Central	-0.004	West South Central	0.018
Mountain	0.022	Mountain	0.008	Mountain	-0.006
Pacific	0.001	Pacific	-0.002	Pacific	-0.036
Black/ African American	-0.035	Black/ African American	-0.023	Black/ African American	-0.064
Asian	-0.085	Asian	-0.055	Asian	-0.098
Other	-0.014	Other	-0.005	Other	-0.025
Hispanic	-0.023	Hispanic	-0.003	Hispanic	-0.015
Presence of Children	-0.010	Presence of Children	-0.007	Presence of Children	-0.020
log(Price of Ice Cream)	-0.001	log(Price of Natural Cheese)	-0.011	log(Price of Processed Cheese)	0.035
log(Price of Greek Yogurt)	0.062	log(Price of Processed Cheese)	0.010	log(Price of Natural Cheese)	-0.004
log(Price of non-Greek Yogurt)	-0.197	log(Price of Conventional Milk)	-0.134	log(Price of Conventional Milk)	-0.775
log(Price of WAC for Ice Cream)	-0.394	log(Price of WAC for Natural Cheese)	0.106	log(Price of WAC for Processed Cheese)	-0.021
Coupon Use for Ice Cream	2.500	Coupon Use for Natural Cheese	0.362	Coupon Use for Processed Cheese	1.189
log(Price of PMA)	-0.781	log(Price of PMA)	-0.520	log(Price of PMA)	0.365
log(Price of WAC for Low-fat Milk)	-0.408	log(Price of WAC for Skim Milk)	-0.202	log(Price of WAC for Whole Milk)	-0.022
Coupon Use for Low-fat Milk	5.599	Coupon Use for Skim Milk	4.993	Coupon Use for Whole Milk	3.947

Appendix A.3 Continued

Greek Yogurt	marginal effect	non-Greek Yogurt	marginal effect
log(household size)	0.066	log(household size)	0.107
log(income)	0.003	log(income)	0.000
log(age)	-0.012	log(age)	-0.013
Education	0.039	Education	0.018
Middle Atlantic	-0.022	Middle Atlantic	-0.013
East North Central	-0.023	East North Central	0.000
West North Central	-0.015	West North Central	0.006
South Atlantic	-0.034	South Atlantic	-0.013
East South Central	-0.050	East South Central	-0.025
West South Central	-0.036	West South Central	-0.007
Mountain	0.003	Mountain	-0.002
Pacific	-0.020	Pacific	-0.002
Black/ African American	-0.061	Black/ African American	-0.037
Asian	-0.055	Asian	-0.036
Other	-0.014	Other	-0.017
Hispanic	0.008	Hispanic	0.014
Presence of Children	0.001	Presence of Children	0.063
log(Price of Greek Yogurt)	-0.640	log(Price of non-Greek Yogurt)	0.018
log(Price of non-Greek Yogurt)	1.161	log(Price of Greek Yogurt)	-0.232
log(Price of Ice Cream)	0.601	log(Price of Ice Cream)	-0.077
log(Price of Conventional Milk)	1.166	log(Price of Conventional Milk)	-0.055
log(Price of WAC for Greek Yogurt)	-0.042	log(Price of WAC for non-Greek Yogurt)	-0.672
Coupon Use for Greek Yogurt	1.327	Coupon Use for non-Greek Yogurt	2.001

Appendix A.3 Continued

Butter	marginal effect	Margarine	marginal effect
log(household size)	0.114	log(household size)	0.136
log(income)	0.004	log(income)	-0.004
log(age)	0.031	log(age)	0.012
Education	0.043	Education	-0.066
Middle Atlantic	-0.004	Middle Atlantic	-0.019
East North Central	-0.010	East North Central	0.026
West North Central	0.004	West North Central	0.027
South Atlantic	-0.036	South Atlantic	0.031
East South Central	-0.066	East South Central	0.085
West South Central	-0.045	West South Central	0.047
Mountain	0.001	Mountain	-0.041
Pacific	-0.022	Pacific	-0.045
Black/ African American	-0.075	Black/ African American	0.058
Asian	-0.088	Asian	-0.101
Other	-0.042	Other	0.002
Hispanic	-0.045	Hispanic	0.020
Presence of Children	-0.013	Presence of Children	-0.031
log(Price of Butter)	0.049	log(Price of Margarine)	-0.222
log(Price of Margarine)	0.684	log(Price of Butter)	-0.162
log(Price of WAC for Butter)	0.477	log(Price of WAC for Margarine)	-0.965
Coupon Use for Butter	2.507	Coupon Use for Margarine	3.167