Journal of Food Distribution Research
Volume 54, Issue 3, pp. 30–65

A Comparison of Demand System Models Peculiar to a Granular Array of Dairy Products

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Abstract

Demand interrelationships for eight dairy categories—margarine and plant-based milk alternatives—were estimated using the Quadratic Almost Ideal Demand System (QUAIDS) and the Barten Synthetic Model (BSM), based on data derived from Nielsen covering the period January 2010 to November 2015. The own-price elasticities, with few exceptions, were in the elastic range. Those derived from the BSM typically were larger than those derived from the QUAIDS. All products considered were necessities. The BSM discerned more statistically significant compensated cross-price elasticities than the QUAIDS. Most of the statistically significant cross-price elasticities from the demand models were positive, indicative of substitutability among the products.

Keywords: dairy products, plant-based milk, Nielsen Homescan panel, QUAIDS, Barten Synthetic Model

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Introduction

The U.S. dairy market was valued at $103 billion in 2020 and is projected to reach $137 billion by 2026, growing at a compound annual growth rate of nearly 5% from 2020 to 2026 (United States Dairy Market Report, 2021). According to the International Dairy Foods Association (IDFA), the incremental contribution of the U.S. dairy industry to the U.S. economy in 2021 was $753 billion (Dykes, 2021). In addition, the U.S. dairy industry supports slightly more than 3 million jobs and contributes 3.5% of the U.S. GDP. Further, dairy products play a key role in the American diet as they contain vital nutrients for the health and maintenance of the human body. Notable nutrients include calcium, vitamin D, protein, and potassium (Bailey et. al, 2010; U.S. Department of Agriculture, 2021). The U.S. Department of Agriculture suggests that diets containing 3 cups of dairy products per day can improve bone mass and bone health (U.S. Department of Agriculture, 2021). In sum, the U.S. dairy industry is not only vital to the health of the U.S. economy but also vital to the health of Americans.

On a per capita consumption basis, the major dairy products in the United States include fluid milk, cheese, butter, yogurt, and ice cream. Based on data from the Economic Research Service, U.S. Department of Agriculture (USDA-ERS, 2023), consumption of fluid milk has been declining steadily from 196 pounds per person annually in 2000 to 134 pounds per person annually in 2021. Consumption of cheese (including both natural cheese and processed cheese) on the other hand has been rising steadily from 29.5 pounds per person annually in 2000 to 38.4 pounds per person annually in 2021. As well, annual per capita consumption of butter has increased sharply since 2000, from 4.5 pounds to 6.5 pounds. Annual per capita consumption of yogurt rose monotonically from 6.5 pounds to 14.9 pounds over the period 2000 to 2014 but has leveled off since then from 13.4 pounds to 14.4 pounds. Finally, annual per capita consumption of ice cream has experienced a decline since 2000 from 22.7 pounds to 18.4 pounds.

Based on per capita consumption patterns previously described, notable changes are evident in the demand for dairy products. Additionally, the plant-based milk industry has grown over the last decade, predominantly driven by Millennials, vegan diets, dietary restrictions, and environmental concerns. In this light, the general objective of this study is to investigate demand interrelationships among different categories of dairy products and plant-based alternatives to milk based on monthly time-series data derived from Nielsen for calendar years 2010[1] to 2015. The specific objectives are as follows:

To estimate the Quadratic Almost Ideal Demand Systems (QUAIDS) and the Barten Synthetic Model (BSM) concerning 10 distinct products: (i) flavored milk, (ii) white milk, (iii) non-Greek yogurt, (iv) Greek yogurt, (v) butter, (vi) natural cheese, (vii) processed cheese, (viii) ice cream, (ix) plant-based milk alternatives, and (x) margarine;

[1] Calendar year 2010 was selected as the starting year because the market shares for Greek yogurt and plant-based milk dairy alternatives were extremely small compared to other dairy categories before 2010.

To derive uncompensated and compensated own-price elasticities as well as expenditure elasticities and income elasticities for these products; and

To analyze the substitutability and complementarity among the 10 dairy and alternative products based on compensated cross-price elasticities.

The information gleaned from the empirical findings of this study will be of interest to different stakeholders. Manufacturers and retailers can employ the estimates of own-price and cross-price elasticities in designing revenue-maximizing pricing strategies as well as inventory management and input procurement plans to adequately respond to price changes associated with dairy products. Policy makers can use the empirical findings to design or revise policies that would help them provide oversight to the dairy industry.

This analysis rests on the use of data from the Nielsen Homescan panel over the period January 2010 to November 2015. As such, this analysis serves as a benchmark for future analyses concerning consumption of dairy products and dairy alternatives. Of particular importance is the fact that demand system analyses associated with different dairy categories in the United States were done at least a decade ago (Chouinard et al., 2010; Davis et al., 2010; Davis et al., 2011a; Davis et al., 2011b). Hence, a need exists to update these demand systems models concerning dairy products. To illustrate, plant-based milk alternatives and Greek yogurt were just introduced to the marketplace around 2010. As such, our contribution serves to provide a more up-to-date demand systems analysis for a granular array of dairy products as well as for plant-based milk alternatives currently lacking in extant literature. Further, with the use of two popular demand systems, we provide a check on the robustness of the empirical results.

Demand System Models

Most of the plethora of previous studies concerning the demand for dairy products have focused on individual dairy products, notably fluid milk (Gould, Cox, and Perali, 1990; Cornick, Cox, and Gould, 1994; Gould, 1996; Davis et al., 2009; Alviola and Capps, 2010; Davis et al., 2012; Dharmasena and Capps, 2012; Li, Peterson, and Xia, 2012; Yang and Dharmasena, 2021), cheese (Maynard, 2000), ice cream (Maynard and Veeramani, 2003; Davis et al., 2009), and yogurt (Dharmasena and Capps, 2014; Robinson, 2017; Keller, 2018).

Over the past three decades, demand analyses concerning dairy products have been conducted to investigate the interrelationships among different dairy categories. In the early studies (Huang, 1985; Heien and Wessells, 1988; Heien and Wessells, 1990; Huang, 1993), the demands of different dairy products were estimated along with other food, such as non-dairy beverages, meat, eggs, etc. According to the U.S. Department of Agriculture Dietary Guidelines, dairy has been listed as an independent food group in the U.S. diet system, along with vegetables, fruits, grains, and protein foods, based on their nutrient-dense forms. Consistent with previous studies, we consider a granular set of dairy products in this research, namely flavored milk, white milk,[2] non-

[2] In the dairy market, white milk could be disaggregated into organic milk and conventional milk based on production methods. Alternatively, white milk could be disaggregated into skim milk (0% fat), low-fat milk (1% or

Greek yogurt, Greek yogurt, natural cheese, processed cheese, ice cream, and butter. We also include plant-based milk alternatives and margarine in our research. Additionally, our analysis is dedicated to products of primary interest to the dairy industry.

Importantly, like Maynard and Liu (1999), Maynard and Veeramani (2003), Chouinard et al. (2010), Dharmasena and Capps (2014), Sarker, Koto, and Cassidy (2015), and Yang and Dharmasena (2021), we avoid the data-censoring problem inherent with cross-sectional studies. In this study, we aggregate monthly expenditures and purchases of dairy products and plant-based milk alternatives made by U.S. households over the period January 2010 to November 2015. This approach circumvents the problem of zero observations concerning purchases that are often encountered when using micro-level (household) data.[3]

To investigate interrelationships among dairy products, the most popular demand system model has been variations of the AIDS model (Heien and Wessells 1988; Heien and Wessells 1990; Maynard and Liu, 1999; Cakir and Balagtas, 2010; Davis et al., 2010; Davis, Yen, Dong, and Blayney, 2011b); a few studies also featured the Barten Synthetic Model (Maynard and Liu, 1999; Maynard and Veeramani, 2003; Sarker, Koto, and Cassidy, 2015). Our work differs from previous studies by utilizing both the Quadratic Almost Ideal Demand System (QUAIDS) and the Barten Synthetic Model (BSM) to analyze the interrelationships among 10 dairy products as well as two alternative product categories. The QUAIDS allows quadratic Engel curves, which permits goods to be luxuries at some income levels and necessities at others. At the same time, the BSM provides more flexibility by nesting four widely used demand systems, the Rotterdam Model, the Almost Ideal Demand System (AIDS), the Central Bureau of Statistics (CBS) Model, and the National Bureau of Research (NBR) Model. With the estimation of these respective demand models, we are positioned to check on the robustness of the empirical results.

QUAIDS (Quadratic Almost Ideal Demand System)

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

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

where:

w_i is the expenditure share on good i,

p_i is the price for good i,

2% fat), and whole milk (3.25% fat) based on the fat content. We used the aggregated white milk category in this research because the prices of these disaggregated milk products were highly correlated.

[3] We recognize and acknowledge that previous studies have found various combinations of demographic variables, such as age, education, race/ethnicity, region, household size, and household income to affect the demand for dairy products. We plan to conduct a future analysis wherein we entertain the use of these sociodemographic variables.

m is the total expenditure,

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

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

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

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

To conform to demand theory, the following constraints are imposed:

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

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

The expenditure as well as uncompensated and compensated price elasticities can be calculated as:

expenditure elasticity for product category i: $\eta_i = \frac{\mu_i}{w_i} + 1$ (4)

uncompensated own-price and cross-price elasticities: $\varepsilon_{ij}^{u} = \frac{\mu_{ij}}{wi} - \delta_{ij}$ (5)

(compensated own-price and cross-price elasticities)[4]: $\varepsilon_{ij}^{c} = \varepsilon_{ij}^{u} + \eta_i w_j$ (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.

BSM (Barten Synthetic Model)

BSM was first developed by Barten (1993). Matsuda (2005) demonstrated that the BSM is not a mere artificial composite of known differential demand systems. The BSM is specified as follows:

[4] Derived from Slutsky's equation.

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

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,

$d \ln q_i$ is the logarithmic differential of the quantity for good i.

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

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

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

The following constraints are imposed to conform to demand theory:

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

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

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

Parameters can be restricted to arrive at nested models within the BSM:

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

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

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

$$\varepsilon_{ij}^{c} = \varepsilon_{ij}^{u} + \eta_i w_j \quad (12)$$

Data

The data used in this study correspond to monthly observations of dairy products and plant-based milk alternatives derived from Nielsen Homescan Panel over the period of January 2010 to November 2015.[5] The respective products are partitioned into 10 categories: (i) flavored milk (mainly chocolate milk), (ii) white milk (both organic and conventional white milk), (iii) non-Greek yogurt, (iv) Greek yogurt, (v) butter, (vi) natural cheese, (vii) processed cheese,[6] (viii) plant-based milk alternatives,[7] (ix) ice cream, and (x) margarine. To the best of our knowledge, we provide the first demand systems analysis incorporating Greek and non-Greek yogurt and plant-based milk alternatives among the conventional set of dairy products. Also, this study represents the initial use of the QUAIDS model in investigating interrelationships of demand among dairy products.

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. Initially, all the purchasing records are aggregated over households for the same month; thus, a total of 71 monthly observations are used for further analysis. Second, the aggregated coupon values per month are subtracted from the aggregated total amount paid per month to derive the aggregated monthly expenditures for each of the respective 10 product categories. Subsequently, we derive monthly expenditure and quantity data per household from January 2010 to November 2015. The number of households who purchased these dairy and alternative product categories differs not only over the 10 respective categories but also over the monthly time periods. As such, the expenditure and quantity data are expressed in terms of dollars and ounces purchased per household per month. Then, the monthly unit values, a proxy for retail prices, for each dairy category are derived by dividing monthly expenditure by monthly quantity.

The construction of unit values is consistent with the methodology proposed by Deaton (1987), which allows the use of expenditure and quantity data from household surveys to estimate a system of demand equations. Indeed, as pointed out by Deaton (1988, 1990, 1997) and Niimi (2005), bias associated with the use of unit values may occur. The bias is attributed to quality variation and reporting errors in expenditures and/or quantities (measurement errors). Deaton (1988) suggested

[5] The Nielsen Homescan Panel did not contain purchasing records for the entire month of December 2015. Thus, November 2015 was set as the end of the monthly time-series data in this analysis.

[6] There are various types of cheeses in the dairy market. We used the definition of processed cheese (pasteurized process cheese) from CFR–Code of Federal Regulations Title 21 U.S. Food and Drug Administration to identify and develop the processed cheese category.

[7] Products of two brands, Blue Diamond and Silk, are used to represent plant-based milk alternatives since these two brands had the largest market shares by far in this category over calendar years 2010 to 2015.

that the bias associated with quality variation makes the demand for a commodity appear to be more elastic, overstating the response of quantity to changes in price.

Gibson and Rozelle (2006) suggested that two types of measurement error bias are evident: (i) attenuation bias because unit values are noisy measures of market prices and (ii) bias due to correlated errors in measuring expenditures and/or quantities. In the case of attenuation bias, Gibson and Rozelle (2006) noted that the bias was in the opposite direction to that attributed to quality variation. If so, then the bias due to quality variation and the bias due to attenuation are offsetting to some degree. However, Gibson and Rozelle (2006) also pointed out that the bias due to correlated errors operated in the opposite direction to attenuation bias. Consequently, the bias due to correlated errors reinforces the bias due to quality effects. Importantly, Gibson and Rozelle (2006) documented that the bias associated with quality variation was relatively minor, also consistent with the finding of Deaton (1997). Bottom line, we recognize these issues in using unit values as proxies for retail prices. We operate on the assumption that the biases previously mentioned are negligible.

Next, all the expenditures of the 10 categories per month are summed to derive the total monthly expenditure. We divide monthly expenditure for each product category by total monthly expenditure to obtain the respective budget shares per month. In the end, the dataset for this analysis includes monthly quantities per household (expressed in ounces), unit values (expressed as $/ounce), monthly expenditures per household (expressed in $), and monthly budget shares from January 2010 to November 2015 (71 observations).

Table 1 shows the market penetration for different dairy products from 2010 to 2015. Market penetration is defined as the number of households who purchase the product divided by the number of households who participated in the Nielsen Homescan Panel in various months of the respective calendar years. Plant-based milk alternatives (e.g., almond milk, oat milk, soy milk, rice milk, coconut milk, and so on) and Greek yogurt have gained in popularity. The market penetration of plant-based milk alternatives increased noticeably from 17% to 29% over the period 2010 to 2015. The market penetration of Greek yogurt increased to 54% in 2014 and 2015, from 20% in 2010, and the market penetration of natural cheese rose modestly from 94% to 96% over this period. On the other hand, the market penetration for white milk declined from 94% to 92%, flavored milk decreased from 28% to 21%, ice cream fell from 75% to 71%, processed cheese declined from 90% to 86%, and non-Greek yogurt decreased from 80% to 72% over the period 2010 to 2015. The market penetration of butter rose from 66% to 71%, but the market penetration for margarine declined from 72% to 61% over the period 2010 to 2015.

Table 1. Market Penetration for Different Dairy Products, 2010 to 2015

Year	White Milk	Flavored Milk	Butter	Ice Cream	Natural Cheese	Processed Cheese	Non-Greek Yogurt	Greek Yogurt	PMA[1]	Margarine
2010	94%	28%	66%	75%	94%	90%	80%	20%	17%	64%
2011	94%	26%	67%	72%	94%	89%	78%	35%	19%	72%
2012	93%	25%	69%	71%	95%	89%	75%	44%	21%	65%
2013	93%	23%	71%	72%	95%	88%	72%	53%	23%	61%
2014	92%	21%	70%	72%	95%	87%	73%	54%	28%	59%
2015	92%	23%	71%	71%	96%	86%	73%	54%	29%	61%

Note: [1] The acronym PMA denotes plant-based milk alternatives. This category includes milk alternatives (predominantly almond milk) manufactured by Blue Diamond and Silk.
Source: Nielsen Homescan Panel, calendar years 2010 to 2015.

Table 2 gives descriptive statistics of quantities (ounces), total expenditures ($), budget shares, and unit values ($/ounce) for the 10 product categories, respectively. The amount purchased per household per month is highest for white milk at 213.80 ounces on average, followed by ice cream at 23.71 ounces, natural cheese at 23.64 ounces, and non-Greek yogurt at 22.54 ounces. Monthly purchases of processed cheese per household (9.43 ounces) are more than 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, butter, and margarine per household are 7.89, 8.28, 7.26, and 9.22 ounces on average, respectively.

The budget shares on average in descending order are as follows: natural cheese 29%, white milk 27%, non-Greek yogurt 10%, processed cheese 9%, ice cream 7%, butter 7%, Greek yogurt 5%, margarine 4%, plant-based milk alternatives 2%, and flavored milk 1%. Meanwhile, the unit values on average over the 71-month 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, margarine 9 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 monthly total expenditures for the 10 product categories per household are $21.30 on average over the period 2010 to 2015. Nominal income per capita[8] over this period is $39,647 on average.

[8] U.S. Bureau of Economic Analysis, Real Disposable Personal Income: Per Capita [A229RX0], retrieved from the Federal Reserve Economic Database (FRED), Federal Reserve Bank of St. Louis.

Table 2. Summary Statistics of Quantities, Expenditures, Budget Shares, Unit Values, Producer Price Index (PPI), and Disposable Personal Income (DPI), January 2010 to November 2015

		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
	Plant-based milk alternatives	8.28	1.50	5.24	11.63
	Ice cream	23.71	3.89	17.15	33.19
	Margarine	9.22	1.46	7.18	13.52
Budget share	Flavored milk	0.01	0.002	0.01	0.02
	White milk	0.27	0.02	0.21	0.30
	Non-Greek yogurt	0.10	0.02	0.06	0.14
	Greek yogurt	0.05	0.02	0.01	0.08
	Butter	0.06	0.02	0.05	0.13
	Natural cheese	0.29	0.03	0.24	0.33
	Processed cheese	0.09	0.01	0.08	0.12
	Plant-based milk alternatives	0.02	0.003	0.01	0.02
	Ice cream	0.07	0.01	0.05	0.10
	Margarine	0.04	0.01	0.03	0.05
Unit values ($/Ounce)	Flavored milk	0.04	0.00	0.03	0.04
	White milk	0.03	0.00	0.02	0.04
	Non-Greek yogurt	0.10	0.00	0.09	0.10
	Greek yogurt	0.18	0.01	0.16	0.21
	Butter	0.19	0.02	0.15	0.26
	Natural cheese	0.26	0.01	0.24	0.30
	Processed cheese	0.21	0.01	0.19	0.23
	Plant-based milk alternatives	0.05	0.00	0.04	0.05
	Ice cream	0.06	0.00	0.05	0.07
	Margarine	0.09	0.01	0.08	0.10
Expenditure ($)	Total expenditure	21.30	1.83	17.04	25.25
Ppi (dec 2000 = 100)	Producer price index	105.92	0.97	103.90	107.20
Per capita Income ($)	Disposable personal income (dpi)	39,647	1193	37,573	41,933

Estimation Issues

Various issues are addressed during the estimation of the respective demand system models: (i) autocorrelation or serial correlation; (ii) endogeneity of total expenditure and prices (unit values); (iii) stationarity; and (iv) seasonality.

Autocorrelation

Because time-series data are used in this research, the presence of serial correlation is considered using the Ljung-Box test (Ljung and Box, 1978; Box et al., 2015) to check on the presence/absence of serial correlation in each of the respective equations of the QUAIDS and the BSM. In general, the respective models assuming the presence of autocorrelation may be specified as follows:

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

where k is the number of lag terms, y_{it} represents the budget share of product category i in period t for the QUAIDS, and y_{it} represents the budget share times the logarithm of the differential of the quantity of product category i for period t for the BSM. $f(x_{it}, \beta)$ is the functional form from equation (1) for the QUAIDS and the function form from equation (9) for the BSM (Berndt and Savin, 1975; Dharmasena and Capps, 2012; Hovhannisyan and Gould, 2014). Upon estimation of the respective models, the Ljung-Box statistics indicate the presence of first-order autoregression processes of disturbance terms (AR(1)) in the QUAIDS, but the absence of any autocorrelation whatsoever in the BSM. The reason for this finding is attributed to the fact that the BSM is expressed in terms of logarithmic differences and not levels, unlike the QUAIDS, which involves levels of budget shares. Owing to adding up, the estimation of a common ρ across the QUAIDS is necessary to mitigate the issue of serial correlation.

Endogeneity

The second issue centers attention on the endogeneity of total expenditure and prices in the QUAIDS and in the BSM.[9] Because total expenditure is defined as the sum of expenditures of each product category, it is reasonable to consider this term endogenous. Following Dhar, Chavas, and Gould (2003) and Lakkakula, Schmitz, and Ripplinger (2016), we specify the auxiliary equation for the total expenditure to deal with the endogeneity issue as follows:

$$\ln m_t = f\ (\ln DPI_t\,, lags\ of \ln m) \tag{14}$$

where $\ln m_t$ is the logarithm of total expenditure at period t, $\ln DPI_t$ is the logarithm of disposable income at period t, and $lags\ of \ln m$ represent the lags of the logarithm of total expenditure. The instrument variables used in this equation are also like those used in the works of Attfield (1985), Capps et al. (1994), and Dharmasena and Capps (2012). 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). Lag lengths of two and three months had similar values associated with these criteria. As exhibited in Table 3, based on the principle of parsimony, a lag of order 2 for $\ln m$ was used in the instrumental variable regression.

[9] In the BSM model, the logarithmic differential of the price $\text{dln}\, p_i$ is used. In practice, $\text{dln}\, p_i \approx \Delta \ln p_i = \ln p_{i,t} - \ln p_{i,t-1}$.

Table 3. Instrumental Variable Estimation Results Concerning Total Expenditure and Prices

Total Expenditure		
Explanatory Variables	**Estimate**	***p*-value**
constant	-4.17	0.14
log $(DPI)_t$	0.48	0.10
log $(\text{Total Expenditure})_{t-1}$	0.35	0.00
log $(\text{Total Expenditure})_{t-2}$	0.36	0.00
Goodness-of-Fit	R^2	0.66
	Adjusted R^2	0.65
	RMSE	0.05
	Durbin Watson	2.16

Log(Flavored Milk Price)			Log(Unflavored Milk Price)		
Explanatory Variables	**Estimate**	***p*-value**	**Explanatory Variables**	**Estimate**	***p*-value**
constant	-2.08	0.26	constant	-8.13	0.06
log $(PPI)_t$	0.31	0.40	log $(PPI)_t$	1.50	0.09
log $(\text{own price})_{t-1}$	**0.80**	**0.00**	log $(\text{own price})_{t-1}$	**0.68**	**0.00**
Goodness-of-Fit	R^2	0.78	Goodness-of-Fit	R^2	0.65
	Adjusted R^2	0.77		Adjusted R^2	0.65
	RMSE	0.02		RMSE	0.05
	Durbin-Watson	1.94		Durbin-Watson	1.92

Log(Non-Greek Yogurt Price)			Log(Processed Cheese Price)		
Explanatory Variables	**Estimate**	***p*-value**	**Explanatory Variables**	**Estimate**	***p*-value**
constant	**-5.29**	**0.02**	constant	**-6.05**	**0.02**
log $(PPI)_t$	**1.00**	**0.02**	log $(PPI)_t$	**1.21**	**0.03**
log $(\text{own price})_{t-1}$	**0.75**	**0.00**	log $(\text{own price})_{t-1}$	**0.74**	**0.00**
Goodness-of-Fit	R^2	0.88	Goodness-of-Fit	R^2	0.83
	Adjusted R^2	0.87		Adjusted R^2	0.83
	RMSE	0.02		RMSE	0.02
	Durbin-Watson	1.99		Durbin-Watson	2.04

Log(Plant-based Alternative Milk Price)			Log(Butter Price)		
Explanatory Variables	**Estimate**	***p*-value**	**Explanatory Variables**	**Estimate**	***p*-value**
constant	**-8.00**	**0.00**	constant	-8.32	0.06
log $(PPI)_t$	**1.43**	**0.00**	log $(PPI)_t$	1.71	0.07
log $(\text{own price})_{t-1}$	**0.57**	**0.00**	log $(\text{own price})_{t-1}$	**0.78**	**0.00**
Goodness-of-Fit	R^2	0.69	Goodness-of-Fit	R^2	0.76
	Adjusted R^2	0.68		Adjusted R^2	0.76

Table 3. Continued

Log(Plant-based Alternative Milk Price)			**Log(Butter Price)**		
Explanatory Variables	**Estimate**	***p*-value**	**Explanatory Variables**	**Estimate**	***p*-value**
	RMSE	0.02		RMSE	0.05
	Durbin-Watson	2.02		Durbin-Watson	1.97

Log(Natural Cheese Price)			**Log(Margarine Price)**		
Explanatory Variables	**Estimate**	***p*-value**	**Explanatory Variables**	**Estimate**	***p*-value**
constant	0.91	0.50	constant	1.18	0.68
log $(PPI)_t$	-0.23	0.44	log $(PPI)_t$	-0.34	0.57
log $(\text{own price})_{t-1}$	**1.13**	**0.00**	log $(\text{own price})_{t-1}$	**0.84**	**0.00**
log $(\text{own price})_{t-2}$	-0.06	0.76	log $(\text{own price})_{t-2}$	**-0.35**	**0.03**
log $(\text{own price})_{t-3}$	-0.20	0.12	log $(\text{own price})_{t-3}$	**0.34**	**0.01**
Goodness-of-Fit	R^2	0.88	Goodness-of-Fit	R^2	0.61
	Adjusted R^2	0.87		Adjusted R^2	0.59
	RMSE	0.02		RMSE	0.04
	Durbin-Watson	2.06		Durbin-Watson	2.05

Log(Greek Yogurt Price)			**Log(Ice Cream Price)**		
Explanatory Variables	**Estimate**	***p*-value**	**Explanatory Variables**	**Estimate**	***p*-value**
constant	3.38	0.14	constant	**-9.69**	**0.00**
log $(PPI)_t$	1.62	0.26	log $(PPI)_t$	**1.94**	**0.00**
log (PPI)t-1	**-4.65**	**0.01**	log $(\text{own price})_{t-1}$	**1.18**	**0.00**
log (PPI)t-2	2.23	0.13	log $(\text{own price})_{t-2}$	**-0.41**	**0.00**
log $(\text{own price})_{t-1}$	**0.80**	**0.00**			
Goodness-of-Fit	R^2	0.89	Goodness-of-Fit	R^2	0.98
	Adjusted R^2	0.88		Adjusted R^2	0.97
	RMSE	0.02		RMSE	0.01
	Durbin-Watson	1.97		Durbin-Watson	2.06

Note: Based on critical values associated with the Durbin-Watson tests, there is not enough evidence to support the existence of serial correlation at the 5% significance level in the respective auxiliary regressions.
Source: Calculations by the authors.

Zhen et al. (2013) argued that using data at the household level makes the issue of price endogeneity inconsequential since purchase decisions typically do not influence market price. However, this analysis rests on the use of data aggregated over households. To mitigate the issue of price (or unit value) endogeneity, following Dhar, Chavas, and Gould (2003) as well as Lakkakula, Schmitz, and Ripplinger (2016), we use reduced-form equations of prices p_{it} (see equation]15]); the natural log of price p_{it} of each product category is regressed on the natural log of the Producer Price Index (PPI) for all commodities, $\ln \text{PPI}_t$ or its lags, as well as lags of the prices of the respective dairy categories. The use of the PPI in this analysis is reflective of supply-side variation in prices and, thus, is most likely to be exogenous. To support this contention, producer price indices were used as instruments in Lakkakula, Schmitz, and Ripplinger (2016).

$$\ln p_{it} = \Gamma\,(\ln \text{PPI}_t\,, \text{lags of PPI, and lags of} \ln p) \quad (15)$$

Like the situation for total expenditure, we used AIC, BIC, adjusted R^2, and RMSE to determine the optimal lags of the instrumental variables, detailed estimation results from equation (15) are shown in Table 3.

To check on the endogeneity of prices and total expenditure, we implement the Durbin–Wu–Hausman (DWH) test. The null hypothesis suggests that the parameter estimates are consistent without accounting for endogeneity (Dhar, Chavas, and Gould, 2003). The test statistic H is computed as follows,

$$H = (\beta - \beta_{IV})'\big(\text{var}(\beta) - \text{var}(\beta_{IV})\big)^{-1}(\beta - \beta_{IV}), \quad (16)$$

where β is the vector of estimated coefficients without controlling for price and expenditure endogeneity, β_{IV} is the vector of estimated coefficients after controlling for endogeneity, and the term $\text{var}(\beta) - \text{var}(\beta_{IV})$ is the difference between the respective variance-covariance matrices. The statistic H is asymptotically distributed as a chi-squared statistic, with degrees of freedom equal to the number of positive diagonal elements of the differenced variance-covariance matrices. The DWH test results are presented in Table 4.

Table 4. Goodness-of-fit Metrics, Durbin-Watson Statistics, and DWH Test Results for the QUAIDS and the Barten Synthetic Model (BSM)

	Category	R-Squared	Adj R-Sq	Durbin-Watson
QUAIDS	Flavored milk	0.95	0.94	2.55
	White milk	0.97	0.96	2.71
	Non-Greek yogurt	0.99	0.98	2.49
	Greek yogurt	0.99	0.98	2.03
	Butter	0.92	0.89	2.36
	Natural cheese	0.98	0.97	2.17
	Processed cheese	0.97	0.96	2.54
	Plant-based milk Alternatives	0.90	0.86	1.74
	Ice cream	0.98	0.97	2.19
	Margarine	0.98	0.97	2.12

Table 4. Continued

	Category	R-Squared	Adj R-Sq	Durbin-Watson
	DWH Test	Degree of Freedom	Chi-squared statistic	p-value
		182	453	0.00
BSM	Flavored milk	0.89	0.85	2.01
	White milk	0.94	0.91	2.30
	Non-Greek yogurt	0.93	0.91	2.00
	Greek yogurt	0.89	0.85	1.55
	Butter	0.86	0.81	1.61
	Natural cheese	0.97	0.96	1.67
	Processed cheese	0.96	0.95	2.54
	Plant-based milk Alternatives	0.80	0.72	1.70
	Ice cream	0.90	0.86	1.95
	Margarine	0.95	0.93	2.25
	DWH Test	Degree of Freedom	Chi-squared statistic	p-value
		156	375	0.00

Notes: Based on critical values associated with the Durbin-Watson tests, there is not enough evidence to support the existence of serial correlation at the 5% significance level in the respective equations.
The demand systems were re-estimated by dropping the equations associated with flavored milk to obtain the goodness-of-fit metrics for ice cream.

Stationarity

According to Matsuda (2006), unless linearly approximated, nonlinear systems including the QUAIDS are not amenable in dealing with nonstationary variables. As such, to handle the nonstationarity issue and to reduce any difficulties in estimation, we linearized the translog price index $\ln a(\boldsymbol{p})$ as follows,

$$\ln a(\boldsymbol{p}) = \sum_i w_{it-1} \ln p_{it} \tag{17}$$

In essence, we used Stone's index to replace $\ln a(\boldsymbol{p})$. To avoid any contemporaneous correlation among the budget shares in Stone's price index and the budget shares as associated with the dependent variables in the QUAIDS model, we modified the Stone index by lagging the budget shares by one period as depicted in equation (17). To preserve nonlinear Engel curves (available upon request), the Cobb-Douglas price aggregator $b(\boldsymbol{p})$ in the QUAIDS was kept and used in the estimation.

Seasonality

Seasonal patterns likely are evident in monthly purchases of the respective product categories. To capture possible seasonality, we included 11 monthly dummy variables in the QUAIDS and the BSM. December serves as the base or reference category for seasonality.

Empirical Results

SAS 9.4 was used to estimate the demand system models based on the iterated seemingly unrelated regression procedure (ITSUR). The equation associated with ice cream was dropped to avoid the singularity of the variance-covariance matrix due to the adding-up constraint. Since two lags of total expenditure and up to three lags of own prices are used in the instrumental regression to circumvent the issue of endogeneity, the number of observations available for use was 68.[10]

Goodness-of-Fit

The goodness-of-fit metrics R^2, adjusted R^2, Durbin-Watson statistics, and DWH test results for the QUAIDS and the BSM are shown in Table 4. For the QUAIDS, the R^2 of all the other categories were above 0.90. The Durbin-Watson statistics ranged from 1.74 to 2.71, indicative of white noise after the AR(1) correction. For the BSM, the R^2 measures ranged from 0.80 (plant-based milk alternatives) to 0.97 (natural cheese). The Durbin-Watson Statistics ranged from 1.55 to 2.54, indicative of the presence of white noise or random patterns in the residuals. The Durbin-Wu-Hausman statistics are statistically significant for both models, which confirm the presence of endogeneity of prices and total expenditure.

Estimated Parameters

In Tables 5 and 6, we exhibit the estimated parameters and associated p-values for the QUAIDS and the BSM, respectively. The level of significance chosen for this analysis is 0.05. For the QUADIS, 15 out of 55 gamma parameters γ_{ij}, 6 out of 10 alpha parameters α_i, and 5 out of 10 beta parameters β_i, were statistically different from zero. Five out of 10 lambda parameters λ_i are significantly different from zero individually, and these parameters were jointly significantly different from zero based on the chi-squared test (see Table 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 was statistically superior to the AIDS.

The estimate of the first-order autocorrelation is specified as rho, and this estimated coefficient of 0.97 was statistically different from zero. Based on joint chi-squared tests, seasonality was evident for all product categories except plant-based milk alternatives. For flavored milk, white milk, non-Greek yogurt, and Greek yogurt, the month with the highest purchase was February, and the month associated with the lowest purchase was December. For natural cheese, the month with the highest purchase was January; the month with the lowest purchase was February. In contrast, the purchases

[10] For the BSM, 67 observations were used due to log differences of quantities, prices, and total expenditure.

for butter, margarine, and processed cheese were highest in December and were lowest in February. Purchases of ice cream were highest in June and lowest in December.

For the BSM, 23 out of 55 beta parameters β_{ij} and 9 out of 10 alpha parameters α_i were significant at the 5% level. In addition, lambda λ and mu μ were statistically significant at the 5% level individually. As mentioned previously, the BSM nests four different models by imposing constraints on λ and μ. The joint test results for the four null hypotheses associated with λ and μ presented in Table 6 indicate that all the respective nested models were not supported by the data. Concerning seasonality, like the QUAIDS, all product categories except plant-based milk alternative revealed 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 was February, and the months associated with the lowest purchases were May, March, January, and January, respectively. Households purchase more butter in November and purchased less in February. Regarding cheese (both natural cheese and processed cheese), the month with the highest purchases was January, and the month with the lowest purchases was February. Purchases of ice cream were highest in June and lowest in November.

Table 5. Parameter Estimates, Standard Errors, and *p*-values for the QUAIDS

	Parameters	**Estimates**	**Std Err**	***p*-value**		**Parameters**	**Estimates**	**Std Err**	***p*-value**
Gamma	**g11**	0.00	0.00	0.19	Gamma	**g710**	-0.01	0.02	0.66
	g12	0.00	0.02	0.80		**g88**	**-0.02**	**0.01**	**0.02**
	g13	0.00	0.02	0.85		**g89**	0.01	0.01	0.47
	g14	0.01	0.01	0.31		**g810**	-0.01	0.01	0.41
	g15	0.00	0.01	0.79		**g99**	-0.02	0.02	0.46
	g16	0.01	0.01	0.69		**g910**	0.01	0.02	0.79
	g17	0.00	0.00	0.28		**g1010**	-0.03	0.02	0.16
	g18	0.00	0.00	0.41					
	g19	0.00	0.00	0.62	Alpha	**a1**	**-0.07**	**0.03**	**0.01**
	g110	0.00	0.01	0.86		**a2**	-0.10	0.30	0.73
	g22	-0.24	0.13	0.08		**a3**	**-0.67**	**0.29**	**0.03**
	g23	**-0.46**	**0.09**	**0.00**		**a4**	-0.15	0.16	0.33
	g24	0.13	0.08	0.11		**a5**	**1.39**	**0.43**	**0.00**
	g25	**0.21**	**0.08**	**0.01**		**a6**	**0.55**	**0.25**	**0.04**
	g26	**0.30**	**0.15**	**0.05**		**a7**	**0.32**	**0.13**	**0.02**
	g27	-0.02	0.07	0.81		**a8**	-0.06	0.05	0.19
	g28	0.01	0.04	0.86		**a9**	**-0.40**	**0.14**	**0.01**
	g29	-0.05	0.07	0.48		**a10**	0.19	0.10	0.06
	g210	**0.11**	**0.04**	**0.01**	Beta	**b1**	0.00	0.02	0.98
	g33	**-0.53**	**0.16**	**0.00**		**b2**	**-0.36**	**0.06**	**0.00**
	g34	**0.22**	**0.10**	**0.04**		**b3**	**-0.44**	**0.08**	**0.00**
	g35	**0.26**	**0.09**	**0.01**		**b4**	0.15	0.09	0.08
	g36	**0.40**	**0.13**	**0.00**		**b5**	**0.21**	**0.08**	**0.01**
	g37	0.03	0.07	0.69		**b6**	**0.32**	**0.10**	**0.00**
	g38	0.01	0.04	0.79		**b7**	0.01	0.07	0.87
	g39	-0.06	0.07	0.36		**b8**	0.01	0.04	0.77
	g310	**0.13**	**0.05**	**0.01**		**b9**	-0.03	0.07	0.63
	g44	-0.11	0.06	0.10		**b10**	**0.13**	**0.04**	**0.00**
	g45	-0.09	0.05	0.11	Lambda	**L1**	0.00	0.00	0.95
	g46	**-0.15**	**0.07**	**0.04**		**L2**	**0.10**	**0.03**	**0.00**
	g47	-0.02	0.03	0.41		**L3**	**0.12**	**0.03**	**0.00**
	g48	0.01	0.02	0.57		**L4**	-0.04	0.02	0.07
	g49	0.04	0.03	0.15		**L5**	**-0.07**	**0.02**	**0.00**
	g410	-0.04	0.03	0.12		**L6**	**-0.09**	**0.04**	**0.03**
	g55	-0.19	0.10	0.06		**L7**	0.00	0.02	0.94
	g56	**-0.16**	**0.07**	**0.03**		**L8**	0.00	0.01	0.78
	g57	0.01	0.04	0.87		**L9**	0.01	0.02	0.51
	g58	0.00	0.02	0.95		**L10**	**-0.03**	**0.01**	**0.00**
	g59	0.02	0.04	0.60					
	g510	**-0.07**	**0.03**	**0.02**		**rho**	**0.97**	**0.00**	**0.01**
	g66	**-0.42**	**0.19**	**0.03**					
	g67	0.05	0.06	0.39					
	g68	0.00	0.04	0.92		**Joint test for Lambda**	**Chi-sq stat**	***p*-value**	
	g69	0.05	0.06	0.45					
	g610	-0.08	0.04	0.08					
	g77	**-0.05**	**0.02**	**0.00**					
	g78	0.01	0.01	0.54					
	g79	0.01	0.01	0.46			**61.12**	**0.00**	

Table 5. Continued

	Parameters	Estimates	Std Err	*p-value*		Parameters	Estimates	Std Err	*p-value*
Seasonality	**m11**[1]	0.001	0.00	0.00		m61	**0.017**	**0.00**	0.00
	m12	0.004	0.00	0.00		m62	**-0.010**	**0.01**	0.08
	m13	0.002	0.00	0.00		m63	**-0.005**	**0.00**	0.14
	m14	0.002	0.00	0.00		m64	**-0.006**	**0.00**	0.10
	m15	0.001	0.00	0.00	Natural	m65	**-0.001**	**0.00**	0.81
Flavored	**m16**	0.002	0.00	0.00	cheese	m66	**-0.004**	**0.00**	0.31
milk	**m17**	0.002	0.00	0.00		m67	**-0.005**	**0.00**	0.15
	m18	0.002	0.00	0.00		m68	**-0.002**	**0.00**	0.52
	m19	0.002	0.00	0.00		m69	**0.003**	**0.00**	0.46
	m110	0.002	0.00	0.00		m610	**-0.003**	**0.00**	0.39
	m111	0.002	0.00	0.00		m611	**-0.003**	**0.00**	0.46
	m21	0.012	0.00	0.00		m71	**-0.001**	**0.00**	0.60
	m22	0.030	0.00	0.00		m72	**-0.024**	**0.00**	0.00
	m23	0.005	0.00	0.14		m73	**-0.011**	**0.00**	0.00
	m24	0.010	0.00	0.00		m74	**-0.015**	**0.00**	0.00
White milk	**m25**	0.013	0.00	0.00	Processed	m75	**-0.008**	**0.00**	0.00
	m26	0.013	0.00	0.00	cheese	m76	**-0.009**	**0.00**	0.00
	m27	0.012	0.00	0.00		m77	**-0.010**	**0.00**	0.00
	m28	0.013	0.00	0.00		m78	**-0.009**	**0.00**	0.00
	m29	0.011	0.00	0.00		m79	**-0.012**	**0.00**	0.00
	m210	0.009	0.00	0.01		m710	**-0.007**	**0.00**	0.00
	m211	0.013	0.00	0.00		m711	**-0.009**	**0.00**	0.00
	m31	0.007	0.00	0.01		m81	**0.000**	**0.00**	0.71
	m32	0.043	0.00	0.00		m82	**0.002**	**0.00**	0.24
	m33	0.018	0.00	0.00		m83	**0.001**	**0.00**	0.18
	m34	0.018	0.00	0.00	Plant-based	m84	**0.002**	**0.00**	0.12
Non-Greek	**m35**	0.014	0.00	0.00	milk alterna-	m85	**0.001**	**0.00**	0.40
yogurt	**m36**	0.017	0.00	0.00	tives (PMA)	m86	**0.002**	**0.00**	0.08
	m37	0.015	0.00	0.00		m87	**0.001**	**0.00**	0.26
	m38	0.013	0.00	0.00		m88	**0.001**	**0.00**	0.18
	m39	0.018	0.00	0.00		m89	**0.001**	**0.00**	0.38
	m310	0.018	0.00	0.00		m810	**0.001**	**0.00**	0.47
	m311	0.012	0.00	0.00		m811	**0.001**	**0.00**	0.34
	m41	0.005	0.00	0.03		m91	**0.005**	**0.00**	0.01
	m42	0.023	0.00	0.00		m92	**0.012**	**0.00**	0.00
	m43	0.009	0.00	0.00		m93	**0.015**	**0.00**	0.00
	m44	0.012	0.00	0.00		m94	**0.015**	**0.00**	0.00
Greek	**m45**	0.009	0.00	0.00		m95	**0.012**	**0.00**	0.00
yogurt	**m46**	0.011	0.00	0.00	Ice cream	m96	**0.019**	**0.00**	0.00
	m47	0.010	0.00	0.00		m97	**0.015**	**0.00**	0.00
	m48	0.009	0.00	0.00		m98	**0.014**	**0.00**	0.00
	m49	0.011	0.00	0.00		m99	**0.004**	**0.00**	0.03
	m410	0.009	0.00	0.00		m910	**0.006**	**0.00**	0.00
	m411	0.007	0.00	0.00		m911	**0.004**	**0.00**	0.04
Butter	**m51**	-0.037	0.00	0.00		m101	**-0.009**	**0.00**	0.00
	m52	-0.071	0.01	0.00		m102	**-0.010**	**0.00**	0.00
	m53	-0.030	0.00	0.00		m103	**-0.005**	**0.00**	0.00
	m54	-0.031	0.00	0.00		m104	**-0.007**	**0.00**	0.00
	m55	-0.034	0.00	0.00		m105	**-0.007**	**0.00**	0.00
	m56	-0.042	0.00	0.00	Margarine	m106	**-0.009**	**0.00**	0.00
	m57	-0.033	0.00	0.00		m107	**-0.007**	**0.00**	0.00
	m58	-0.034	0.00	0.00		m108	**-0.006**	**0.00**	0.00
	m59	-0.032	0.00	0.00		m109	**-0.005**	**0.00**	0.00
	m510	-0.029	0.00	0.00		m1010	**-0.006**	**0.00**	0.00
	m511	-0.024	0.00	0.00		m1011	**-0.004**	**0.00**	0.00

Table 5. Continued

		Chi-Squared Stat	*p*-value
Joint test for seasonality			
	Flavored milk	48.15	0.00
	White milk	60.01	0.00
	Non-Greek yogurt	177.14	0.00
	Greek yogurt	69.01	0.00
	Butter	183.10	0.00
	Natural cheese	81.36	0.00
	Processed cheese	189.10	0.00
	PMA	7.60	0.74
	Ice cream	441.89	0.00
	Margarine	156.76	0.00

Note: Bold numbers indicate significance at the 5% level.
[1] 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, and (10) margarine.
Source: Estimation done via the use of SAS 9.4.

Table 6. Parameter Estimates, Standard Errors, and *p*-values for the BSM

	Parameters	Estimates	Std Err	*p*-value		Parameters	Estimates	Std Err	*p*-value
Beta	**b11**	0.01	0.00	0.08	Alpha	**a1**	**-0.01**	**0.00**	**0.00**
	b12	**-0.01**	**0.00**	**0.00**		**a2**	**-0.23**	**0.04**	**0.00**
	b13	0.00	0.00	0.42		**a3**	**-0.08**	**0.02**	**0.00**
	b14	0.00	0.00	0.56		**a4**	**-0.06**	**0.01**	**0.00**
	b15	0.00	0.00	0.07		**a5**	0.03	0.03	0.36
	b16	0.00	0.00	0.92		**a6**	**-0.14**	**0.04**	**0.00**
	b17	0.00	0.00	0.39		**a7**	**-0.04**	**0.01**	**0.01**
	b18	0.00	0.00	0.09		**a8**	**-0.02**	**0.00**	**0.00**
	b19	**-0.01**	**0.00**	**0.02**		**a9**	**-0.05**	**0.01**	**0.00**
	b110	**0.02**	**0.00**	**0.00**		**a10**	**-0.02**	**0.01**	**0.00**
	b22	**0.26**	**0.03**	**0.00**	Lambda	**L**	**1.62**	**0.13**	**0.00**
	b23	**-0.05**	**0.01**	**0.00**	mu	**mu**	**1.72**	**0.15**	**0.00**
	b24	**-0.04**	**0.01**	**0.00**					
	b25	0.01	0.01	0.49					
	b26	**-0.10**	**0.01**	**0.00**	**Joint test**	**H_0:**	**Chi-sq stat**	***p*-value**	
	b27	**-0.03**	**0.01**	**0.00**	Rotterdam	**L=0,mu=0**	**321.08**	**0.00**	
	b28	**-0.01**	**0.00**	**0.01**	AIDS	**L=1,mu=1**	**51.99**	**0.00**	
	b29	**-0.03**	**0.01**	**0.00**	CBS	**L=1,mu=0**	**171.3**	**0.00**	
	b210	**-0.01**	**0.00**	**0.00**	NBR	**L=0,mu=1**	**196.32**	**0.00**	
	b33	0.00	0.02	0.98					
	b34	**0.03**	**0.01**	**0.04**					
	b35	**0.04**	**0.01**	**0.00**					
	b36	-0.01	0.01	0.47					
	b37	**0.03**	**0.01**	**0.01**					
	b38	-0.01	0.01	0.23					
	b39	**-0.04**	**0.02**	**0.01**					
	b310	0.01	0.01	0.21					
	b44	-0.03	0.02	0.11					
	b45	0.02	0.01	0.10					

Table 6. Continued

	Parameters	Estimates	Std Err	*p*-value		Parameters	Estimates	Std Err	*p*-value
	b46	-0.01	0.01	0.46					
	b47	0.01	0.01	0.65					
	b48	0.01	0.01	0.12					
	b49	0.01	0.01	0.29					
	b410	0.01	0.01	0.41					
	b55	**-0.11**	**0.03**	**0.00**					
	b56	**0.04**	**0.01**	**0.00**					
	b57	0.00	0.01	0.59					
	b58	0.00	0.00	0.41					
	b59	0.01	0.01	0.25					
	b510	**-0.01**	**0.00**	**0.02**					
	b66	0.03	0.04	0.49					
	b67	**0.04**	**0.01**	**0.01**					
	b68	0.01	0.01	0.21					
	b69	0.00	0.02	0.85					
	b610	0.01	0.01	0.22					
	b77	**-0.04**	**0.02**	**0.02**					
	b78	0.01	0.01	0.26					
	b79	0.02	0.01	0.13					
	b710	**-0.03**	**0.01**	**0.00**					
	b88	-0.01	0.01	0.34					
	b89	0.00	0.01	0.84					
	b810	0.00	0.00	0.60					
	b99	0.02	0.02	0.32					
	b910	**0.01**	**0.01**	**0.05**					
	b1010	**0.26**	**0.03**	**0.00**					
Seasonal-ity	m11	0.000	0.000	0.08	Natural cheese	m61	**0.018**	**0.002**	**0.00**
Flavored	m12	**0.001**	**0.000**	**0.01**		m62	**-0.015**	**0.003**	**0.00**
milk	m13	0.000	0.000	0.11		m63	0.000	0.002	0.94
	m14	0.000	0.000	0.08		m64	**-0.008**	**0.002**	**0.00**
	m15	**-0.001**	**0.000**	**0.01**		m65	0.003	0.002	0.16
	m16	0.000	0.000	0.14		m66	**-0.004**	**0.002**	**0.05**
	m17	**0.000**	**0.000**	**0.04**		m67	-0.001	0.002	0.39
	m18	0.000	0.000	0.28		m68	-0.001	0.002	0.56
	m19	**0.000**	**0.000**	**0.02**		m69	0.003	0.002	0.06
	m110	**0.000**	**0.000**	**0.03**		m610	0.001	0.002	0.66
	m111	**0.001**	**0.000**	**0.00**		m611	-0.003	0.002	0.13
White milk	m21	-0.001	0.002	0.72	Processed cheese	m71	**0.009**	**0.001**	**0.00**
	m22	**0.012**	**0.003**	**0.00**		m72	**-0.010**	**0.002**	**0.00**
	m23	**-0.012**	**0.002**	**0.00**		m73	-0.002	0.001	0.15
	m24	0.004	0.003	0.11		m74	**-0.008**	**0.001**	**0.00**
	m25	-0.004	0.002	0.11		m75	0.002	0.001	0.12
	m26	0.000	0.002	0.86		m76	0.001	0.001	0.19
	m27	-0.004	0.002	0.07		m77	0.000	0.001	0.65
	m28	0.001	0.002	0.58		m78	-0.001	0.001	0.63
	m29	-0.001	0.002	0.79	Plant-based	m79	**-0.002**	**0.001**	**0.05**
	m210	**-0.007**	**0.002**	**0.00**	milk alter-	m710	**0.004**	**0.001**	**0.00**
	m211	0.000	0.002	0.92	natives	m711	0.000	0.001	0.83
Non-Greek	m31	**-0.009**	**0.002**	**0.00**	(PMA)	m81	-0.001	0.000	0.16
yogurt	m32	**0.020**	**0.003**	**0.00**		m82	0.001	0.001	0.17

Table 6. Continued

	Parameters	Estimates	Std Err	*p*-value		Parameters	Estimates	Std Err	*p*-value
	m33	0.002	0.002	0.40	Alter-natives	**m83**	0.000	0.000	0.96
	m34	0.004	0.002	0.06		**m84**	**0.002**	**0.001**	**0.00**
	m35	-0.003	0.002	0.16		**m85**	-0.001	0.000	0.15
	m36	-0.002	0.002	0.40		**m86**	0.001	0.000	0.09
	m37	-0.003	0.002	0.09		**m87**	-0.001	0.000	0.13
	m38	**-0.003**	**0.002**	**0.05**		**m88**	0.001	0.000	0.15
	m39	0.001	0.002	0.46		**m89**	0.000	0.000	0.88
	m310	0.000	0.002	0.85		**m810**	0.000	0.000	0.29
	m311	**-0.004**	**0.002**	**0.02**		**m811**	0.000	0.000	0.51
Greek yogurt	**m41**	**-0.004**	**0.001**	**0.01**	Ice cream	**m91**	**-0.004**	**0.001**	**0.00**
	m42	**0.013**	**0.002**	**0.00**		**m92**	-0.004	0.002	0.06
	m43	0.001	0.002	0.63		**m93**	**0.005**	**0.001**	**0.00**
	m44	**0.006**	**0.002**	**0.00**		**m94**	**0.007**	**0.001**	**0.00**
	m45	0.000	0.001	0.79		**m95**	**0.003**	**0.001**	**0.02**
	m46	0.000	0.001	0.74		**m96**	**0.008**	**0.001**	**0.00**
	m47	0.000	0.001	0.78		**m97**	**0.005**	**0.001**	**0.00**
	m48	0.000	0.001	0.99		**m98**	**0.003**	**0.001**	**0.01**
	m49	0.002	0.001	0.20		**m99**	**-0.007**	**0.001**	**0.00**
	m410	-0.001	0.001	0.39		**m910**	**-0.005**	**0.001**	**0.00**
	m411	-0.002	0.001	0.15		**m911**	**-0.007**	**0.001**	**0.00**
Butter	**m51**	-0.005	0.004	0.24	Margarine	**m101**	**-0.003**	**0.001**	**0.00**
	m52	**-0.016**	**0.006**	**0.02**		**m102**	-0.001	0.001	0.19
	m53	0.005	0.005	0.29		**m103**	0.001	0.001	0.25
	m54	-0.006	0.005	0.29		**m104**	**-0.002**	**0.001**	**0.00**
	m55	0.001	0.005	0.85		**m105**	**-0.001**	**0.001**	**0.05**
	m56	-0.002	0.004	0.57		**m106**	**-0.002**	**0.001**	**0.01**
	m57	0.005	0.004	0.22		**m107**	0.000	0.001	0.69
	m58	0.001	0.004	0.83		**m108**	0.000	0.001	0.60
	m59	0.001	0.004	0.73		**m109**	0.001	0.001	0.07
	m510	**0.010**	**0.004**	**0.02**		**m1010**	0.000	0.001	0.49
	m511	**0.013**	**0.004**	**0.00**		**m1011**	**0.002**	**0.001**	**0.00**

Seasonality		**Chi-squared stat**	***p*-value**
	Flavored milk	**42.00**	**0.00**
	White milk	**46.51**	**0.00**
	Non-Greek Yogurt	**103.62**	**0.00**
	Greek yogurt	**71.19**	**0.00**
	Butter	**27.04**	**0.00**
	Natural cheese	**149.50**	**0.00**
	Processed cheese	**147.68**	**0.00**
	Plant-based milk alternatives	16.49	0.12
	Ice cream	**225.61**	**0.00**
	Margarine	**100.49**	**0.00**

Note: Bold numbers indicate significance at the 5% level.
Source: Estimation done via the use of SAS.9.4.

Comparison of Elasticities Across Models

The uncompensated, compensated price elasticities and expenditure elasticities were calculated based on equations (4), (5), and (6) for the QUAIDS and based on equations (10), (11), and (12) for the BSM. Note that the respective elasticities depend not only on the estimated parameters but also on prices, total expenditure, and budget shares. The compensated price elasticities as well as the expenditure and income elasticities calculated at the sample means for the QUAIDS and the BSM are presented in Tables 7 and 8, respectively. In Table 9, we compare the compensated own-price elasticities and income elasticities between the QUAIDS and the BSM. The uncompensated own-price and cross-price elasticities are available from the authors upon request.

Table 7. Compensated Own-Price and Cross-Price Elasticities as well as Expenditure and Income Elasticities for the QUAIDS

Good *i* / **Good *j***	**Flavored Milk**	**White Milk**	**Non-Greek Yogurt**	**Greek Yogurt**	**Butter**	**Natural Cheese**	**Processed Cheese**	**PMA**	**Ice Cream**	**Margarine**	**Expenditure Elasticity**	**Income Elasticity**
Flavored milk	**-1.31**	-0.27	0.32	**0.50**	0.13	0.39	-0.29	-0.16	-0.13	-0.08	**1.04**	0.50
White milk	**0.25**	**-0.38**	0.05	**0.23**	**0.34**	**0.29**	**0.17**	**0.25**	0.19	**0.25**	**1.00**	0.48
Non-Greek yogurt	**0.12**	**-0.48**	**-1.33**	**0.54**	**0.50**	**0.55**	0.31	0.06	-0.23	-0.04	**0.87**	0.42
Greek yogurt	**0.18**	-0.10	**1.07**	**-1.92**	-0.12	-0.43	-0.33	**0.34**	**0.64**	0.15	**1.04**	0.50
Butter	0.05	0.24	0.26	-0.15	**-1.66**	0.46	**0.37**	0.11	-0.03	0.15	0.60	0.29
Natural cheese	**0.30**	**0.30**	**0.42**	**0.20**	**0.36**	**-1.26**	**0.50**	**0.31**	**0.35**	**0.37**	**0.99**	0.47
Processed cheese	**0.08**	-0.15	**0.37**	-0.04	0.03	**0.69**	**-1.51**	**0.17**	0.27	0.01	**1.16**	0.56
PMA	-0.11	-0.18	-0.07	0.82	0.20	0.33	0.30	**-2.17**	0.41	-0.41	**1.07**	0.52
Ice cream	0.06	-0.16	-0.26	**0.53**	-0.08	0.31	0.17	0.18	**-1.09**	-0.02	**1.17**	0.56
Margarine	0.04	0.04	-0.16	0.24	-0.30	**0.53**	-0.21	-0.13	0.04	**-0.85**	**1.33**	0.64

Note: Bold numbers indicate significance at the 5% level.
Source: Calculations by the authors.

Table 8. Compensated Own-Price and Cross-Price Elasticities As Well As Expenditure and Income Elasticities for the BSM

Good *i* / Good *j*	Flavored Milk	White Milk	Non-Greek Yogurt	Greek Yogurt	Butter	Natural Cheese	Processed Cheese	PMA	Ice Cream	Margarine	Expenditure Elasticity	Income Elasticity
Flavored milk	**-1.28**	-0.08	-0.07	0.17	**0.32**	**0.54**	0.01	-0.28	**-0.53**	**1.25**	**0.63**	0.30
White milk	0.00	**-0.29**	0.02	**-0.05**	**0.15**	**0.15**	**0.06**	0.01	0.01	0.02	**0.78**	0.38
Non-Greek yogurt	-0.01	0.05	**-1.53**	**0.31**	**0.47**	**0.43**	**0.52**	-0.06	-0.26	**0.15**	**0.88**	0.42
Greek yogurt	0.05	**-0.29**	**0.64**	**-2.23**	**0.45**	0.30	0.27	0.23	0.46	0.18	**0.48**	0.23
Butter	**0.07**	**0.60**	**0.74**	**0.33**	**-3.18**	**1.13**	0.10	0.08	0.29	-0.08	**2.07**	0.99
Natural cheese	**0.03**	**0.14**	**0.15**	0.05	**0.26**	**-1.12**	**0.29**	**0.06**	**0.11**	**0.10**	**1.16**	0.56
Processed cheese	0.00	**0.18**	**0.57**	0.14	0.07	**0.90**	**-1.96**	0.11	**0.28**	**-0.22**	**1.23**	0.59
PMA	-0.21	0.09	-0.33	0.61	0.27	**0.96**	0.55	**-2.07**	0.22	-0.04	**0.56**	0.27
Ice cream	**-0.10**	0.05	-0.38	0.33	**0.28**	**0.44**	**0.38**	0.06	**-1.26**	**0.27**	**0.87**	0.41
Margarine	**0.44**	0.12	**0.39**	0.23	-0.14	**0.73**	**-0.53**	-0.02	**0.48**	**-1.21**	**1.12**	0.54

Note: Bold numbers indicate significance at the 5% level. Source: Calculations by the authors.

Table 9. Comparison of Compensated and Uncompensated Own-Price Elasticities as well as Income Elasticities between the QUAIDS and the BSM

		QUAIDS	**BSM**
Uncompensated own-price elasticity	Flavored milk	-1.32	-1.29
	White milk	-0.64	-0.51
	Non-Greek yogurt	-1.42	-1.63
	Greek yogurt	-1.97	-2.25
	Butter	-1.70	-3.32
	Natural cheese	-1.55	-1.46
	Processed cheese	-1.62	-2.08
	PMA	-2.19	-2.08
	Ice cream	-1.17	-1.32
	Margarine	-0.90	-1.25
Compensated own-price elasticity	Flavored milk	-1.31	-1.28
	White milk	-0.38	-0.29
	Non-Greek yogurt	-1.33	-1.53
	Greek yogurt	-1.92	-2.23
	Butter	-1.66	-3.18
	Natural cheese	-1.26	-1.12
	Processed cheese	-1.51	-1.96
	PMA	-2.17	-2.07
	Ice cream	-1.09	-1.26
	Margarine	-0.85	-1.21
Income elasticity	Flavored milk	0.50	0.30
	White milk	0.48	0.38
	Non-Greek yogurt	0.42	0.42
	Greek yogurt	0.50	0.23
	Butter	0.29	0.99
	Natural cheese	0.47	0.56
	Processed cheese	0.56	0.59
	PMA	0.52	0.27
	Ice cream	0.56	0.41
	Margarine	0.64	0.54

Compensated Own-Price Elasticities

As expected, the compensated own-price elasticities for both demand systems were negative, statistically significant at the 5% level.[11] Both systems satisfied the negativity condition from the demand theory. In both models, compensated own-price elasticities were greater than 1 for most product categories except white milk and margarine in the QUAIDS, and white milk only in the BSM. As such, households were quite sensitive to changes in prices except for white milk.

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

For the QUAIDS, the compensated own-price elasticities ranged from -0.38 (white milk) to -2.17 (plant-based milk alternatives). In the case of the BSM, the compensated own-price elasticities ranged from -0.29 (white milk) to -3.18 (butter). Compared to the QUAIDS, the BSM results in larger compensated own-price elasticities in magnitude for most of the categories, including non-Greek yogurt, Greek yogurt, processed cheese, ice cream, margarine, and butter. To illustrate, the compensated own-price elasticities for butter from the QUAIDS model and the BSM model were -1.66 and -3.18, respectively.

Expenditure and Income Elasticities

The expenditure elasticities for both demand systems were not only positive but also statistically significant at the 5% level, except for butter in the QUAIDS. We derived the income elasticities using equation (18) as follows:

$$IE_i = \frac{\%\Delta\ \text{Total Expenditure}}{\%\Delta\ \text{Income}} \times \frac{\%\Delta\ \text{Quantity Demanded}_i}{\%\Delta\ \text{Total Expenditure}} = 0.48 \times \varepsilon_i, \qquad (18)$$

where IE_i is the income elasticity for product category i, ε_i is expenditure elasticity derived from equations (4) and (11), 0.48 is the estimated coefficient from equation (14), and %Δ represents the percentage change.

For the respective demand system models, all product categories in both models were estimated to be necessities. The income elasticities for the QUAIDS ranged from 0.29 (butter) to 0.64 (margarine). The income elasticities for the BSM ranged from 0.23 (Greek yogurt) to 0.99 (butter).

Compensated Cross-Price Elasticities

In the QUAIDS, 34 out of 90 compensated cross-price elasticities were statistically significant at the 5% level. Non-Greek yogurt was a complement to white milk. But the remaining 33 statistically significant cross-price elasticities were positive, indicative of substitution relationships among the product categories.

Flavored milk was a substitute for white milk, non-Greek yogurt, Greek yogurt, natural cheese, and processed cheese, while white milk was a substitute for natural cheese. Non-Greek yogurt was a substitute for Greek yogurt, natural cheese, and processed cheese, while Greek yogurt was a substitute for flavored milk, white milk, non-Greek yogurt, natural cheese, and ice cream. Butter was a substitute for white milk, non-Greek yogurt, and natural cheese. Natural cheese was a substitute for white milk, non-Greek yogurt, processed cheese, and margarine. Processed cheese was a substitute for white milk, butter, and natural cheese. Ice cream was a substitute for white milk, Greek yogurt, and natural cheese. Plant-based milk alternatives were a substitute for white milk, Greek yogurt, natural cheese, and processed cheese. In the QUAIDS, substitutability between margarine and butter was not evident, but margarine was a substitute for white milk and natural cheese.

In the BSM, 45 out of 90 compensated cross-price elasticities were statistically significant at the 5% level. Six of these statistically significant compensated cross-price elasticities were negative, indicative of complementary relationships. Thirty-nine of these statistically significant cross-price elasticities were positive, indicative of substitution relationships among the product categories. Consequently, the BSM was able to discern more statistically significant compensated cross-price elasticities than the QUAIDS.

Flavored milk and ice cream were complements, Greek yogurt and white milk were complements, while processed cheese and margarine were complements. Flavored milk was a substitute for butter, natural cheese, and margarine. White milk was a substitute for butter, natural cheese, and processed cheese. Not unexpectedly, non-Greek yogurt and Greek yogurt were substitutes. Non-Greek was also a substitute for butter, natural cheese, processed cheese, and margarine. Additionally, Greek yogurt and butter were substitutes. Not surprisingly, natural cheese and processed cheese were substitutes. Further, natural cheese was a substitute for flavored milk, white milk, non-Greek yogurt, plant-based milk alternatives, ice cream, and margarine. Butter was a substitute for flavored milk, white milk, non-Greek yogurt, Greek yogurt, natural cheese, and ice cream. Processed cheese was a substitute for white milk, non-Greek yogurt, and ice cream. Plant-based milk alternatives were a substitute for natural cheese. Ice cream was a substitute for natural cheese, processed cheese, and margarine.

The similarity of the own-price and cross-price elasticities between the respective models is indicative of the robustness of the findings. However, notable differences were observed across the two models in some instances, such as the compensated own-price elasticity for butter and the income elasticities for butter, Greek yogurt, and plant-based milk alternatives. Unlike the BSM, the QUAIDS model captured the presence of quadratic Engel curves, and its nonlinear property required more iterations to deal with estimation issues. According to findings from Pashardes (1993), Moschini (1995), and Barnett and Seck (2008), the application of Stone's Price Index to linearize the model could cause estimation bias.

Standard multivariate regression model selection criteria, such as Likelihood Ratio, Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC), are not applicable to compare the performance between these two models due to the different dependent variables. In general, the findings from the two popular models are robust and provide estimation ranges for the respective elasticities gleaned from this analysis.

The set of products associated with our analysis is unique among corresponding studies in the extant literature. In Table 10, we compare the results from our study with previous research. Our own-price elasticities for white milk were estimated to be less than 1, different from the findings of Davis et al. (2010), but consistent with the findings of Maynard and Liu (1999). Our own-price elasticities for butter were greater than 1, inconsistent with Maynard and Liu (1999), but in accord with Yen, Kan, and Su (2002) and Davis et al. (2010), though greater in magnitude especially in the BSM model. Our own-price elasticities for natural cheese, processed cheese, margarine, and ice cream were in accord with those reported by Davis et al. (2009, 2010, 2011a, and 2011b).

Finally, our own-price elasticities for plant-based milk alternatives were much greater in magnitude than those reported by Yang and Dharmasena (2021).

Table 10. Comparison of Models, Data, Dairy Products, Compensated Own-Price Elasticities, and Income/Expenditure Elasticities with Previous Studies

Study	Model	Data	Dairy Products	Own-price Elasticity	Income / Expenditure Elasticity
Our study	QUAIDS; BSM[a] models	Time-series data, Monthly Nielsen Homescan data 2010–2015	Flavored milk	-1.31 (-1.28[a])	0.50 (0.30[a])
			White milk	-0.38 (-0.29[a])	0.48 (0.38[a])
			Non-Greek yogurt	-1.33 (-1.53[a])	0.42 (0.42[a])
			Greek yogurt	-1.92 (-2.23[a])	0.50 (0.23[a])
			Butter	-1.66 (-3.18[a])	0.29 (0.99[a])
			Natural cheese	-1.26 (-1.12[a])	0.47 (0.56[a])
			Processed cheese	-1.51 (-1.96[a])	0.56 (0.59[a])
			PMA	-2.17 (-2.07[a])	0.52 (0.27[a])
			Ice cream	-1.09 (-1.26[a])	0.56 (0.41[a])
			Margarine	-0.85 (-1.21[a])	0.64 (0.54[a])
Maynard and Liu (1999)	Double-log model/ Linearized AIDS model[c]/ NBR[d]	Time series data, weekly Nielsen Homescan data 1996–1998	White milk	-0.54 (-0.63[c], -0.78[d])	
			Flavored milk	-1.41 (-1.40[c], -1.47[d])	
			Chunk cheese	-2.18 (-1.96[c], -3.03[d])	
			Sliced cheese	-1.64 (-1.72[c], -2.08[d])	
			Snack cheese	-0.58 (-1.68[c], -0.99[d])	
			Shredded cheese	-1.35 (-1.70[c], -2.66[d])	
			Butter	-0.63 (-0.19[c], -2.33[d])	
			Ice cream	-0.88 (-0.65[c], -1.65[d])	
			Frozen yogurt	-1.31 (-1.49[c], -1.64[d])	
			Frozen novelties	-2.99 (-3.39[c], -3.18[d])	
Yen et al. (2002)	A censored translog demand system	Cross-sectional data, the 1987–1988 Nationwide Food Consumption Survey	Butter	-1.13	1.00
			Margarine	-0.99	1.00
Davis et al. (2009)	A censored translog demand system	Cross-sectional data, 2005 Nielsen Homescan	Bulk ice cream	-1.00	1.01
			Ice milk	-1.28	0.84
			Ice cream novelties	-1.96	0.50
Davis et al. (2010)	Censored AIDS model	Cross-sectional data, 2007 Nielsen Homescan	Bulk ice cream	-0.91	1.01
			Sherbet/ice milk	-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

Table 10. Continued

Study	Model	Data	Dairy Products	Own-price Elasticity	Income / Expenditure Elasticity
			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
Davis et al. (2011)	Censored AIDS model	Cross-sectional data, 2006 Nielsen Homescan	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 et al. (2012)	AIDS model	Cross-sectional data, 2007 Nielsen Homescan	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
Robinson (2017)	Single equation estimation[e]/ Seemingly unrelated regression[f]	Time series data, weekly Nielsen Homescan 2009-2011	Chobani yogurt	-1.77[e] (-2.64[f])	0.48[e] (2.89[f])
			Dannon yogurt	-1.42[e] (-1.43[f])	-1.36[e] (2.34[f])
			Yoplait yogurt	-0.41[e] (-0.37[f])	0.11[e] (1.98[bf])
			Stonyfield yogurt	-0.79[e] (-0.86[f])	-4.06[e] (1.64[bf])
			Private label yogurt	-0.14[e] (-0.19[f])	0.99[e] (0.38[bf])
Yang and Dharmasena (2021)	Hedonic BSM model	Time series data, Monthly Nielsen Homescan 2004-2015	Almond milk	-0.12	3.60
			Soy milk	-0.25	10.07
			Rice milk	-0.01	2.31
			2% milk	-0.11	0.83
			1% milk	-0.15	1.14
			Fat-free milk	-0.14	0.57
			Whole milk	-0.12	0.55

Concluding Remarks

In this study, the QUAIDS and the BSM were utilized to investigate the demand for 10 products related to the dairy industry based on monthly time-series data through January 2010 to November 2015, derived from Nielsen Homescan Panels. Issues such as serial correlation, endogeneity of total expenditure and prices, stationarity, and seasonality were addressed during the estimation process. In general, the empirical results were robust for the most part across the respective models.

In both models, seasonality was evident for all dairy categories except for plant-based milk alternatives. Concerning compensated own-price elasticities, both models revealed that the demands for the respective dairy products were elastic except for white milk. In the QUAIDS model, the demand for margarine was inelastic, while the BSM revealed the opposite. The own-price elasticities derived from the BSM were larger than those derived from the QUAIDS in general. Hence, the appropriate strategy for stakeholders in the dairy industry in downstream markets to increase revenue in the short run is to lower prices. For white milk, the appropriate strategy to increase revenue is to raise prices, holding all other factors constant.

Divergences of the expenditure elasticities were evident for Greek yogurt, butter, and plant-based milk alternatives across the models. Nevertheless, for the respective demand system models, all product categories were necessities. As such, changes in income are not likely to provide notable impacts on the demand for the products in question.

The BSM was able to discern more statistically significant compensated cross-price elasticities than the QUAIDS. Across the respective models, most of the statistically significant cross-price elasticities were positive, indicative of substitution relationships among the products considered in this analysis. In the QUAIDS, white milk, Greek yogurt, and plant-based milk alternatives were substitutes. But this finding was not evident in the BSM. Going forward, additional work needs to consider the substitutability of these key products.

Several takeaways are evident from this research. To better understand the demand for dairy products, it is necessary to disaggregate into various segments and to consider plant-based milk alternatives. This disaggregation more accurately captures the reality of what consumers face when shopping at various retail outlets. A fundamental economic principle associated with own-price elasticities is that the greater the number of substitutes for any product, the greater the magnitude of the own-price elasticity. Based on the substitution relationships previously described among the various products considered in this analysis, the magnitudes of the estimated own-price elasticities reported are consistent with this economic principle.

Indeed, for future research, the set of dairy products could be expanded to include white milk and flavored milk delineated by fat type (fat-free, 1%, 2%, and whole), organic milk, cottage cheese, and specific types of natural and processed cheeses as well as specific types of plant-based milk alternatives. Potential issues, however, with this expansion include degrees-of-freedom and degrading collinearity. In addition, including the prices of other desserts in the demand equation for ice cream might be worthwhile.

A statistical comparison of the empirical results based on multivariate regression model selection criteria is inapplicable due to the different dependent variables across the two models. We plan to conduct a comparison between the two models using the cross-validation technique in machine learning to evaluate the performance of the models as a future study.

Our study does not capture the impact of sociodemographic characteristics of households. For future work, we plan to use the Exact Affine Stone Index (EASI) model developed by Pendakur (2009) to examine the impacts of the sociodemographic characteristics of different households. In this way, we are positioned to replicate our analysis at the household level and not aggregate across households.

Further, the data indigenous to our study cover the period January 2010 to November 2015. To conduct a further check on the robustness of the results, it is worthwhile to update the analysis with more recent data, particularly to capture the impact of the pandemic on the demand for the dairy products considered in this analysis. Finally, our study fails to address the impacts of branded or generic advertising on the demands for the respective products. Hence, additional research incorporating these expenditures merits consideration. The issue with this suggestion for future research is the availability of generic and branded advertising expenditures.

Despite these limitations, we provide a definitive more up-to-date picture of demand interrelationships among dairy products and plant-based milk alternatives (primarily almond milk) currently lacking in the extant literature. Moreover, the general similarity of the empirical results from the two widely different demand system models provides more confidence in the findings. Going forward, we recommend continued use of the QUAIDS and the BSM in considering demand interrelationships among dairy products using time-series data. Finally, our analysis serves as a baseline for future research in updating the estimation of these demand interrelationships.

Disclaimer

The researchers' 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 the 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.

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