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Assessing Demand Interrelationships for a Disaggregated Set of Dairy Milk Products and Plant-Based Milk Alternatives

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An EASI model is adopted to investigate the demand structure for dairy and non-dairy milk types in the United States, using weekly time-series data from January 2017 to August 2023. The demands for almond, cashew, and oat plant-based milk alternatives (PBMA) and lactose-free and traditional white milk are elastic, but inelastic for coconut, rice, and soy PBMA and organic milk. Almond and oat are complements, while cashew and coconut are substitutes. Lactose-free milk, traditional white and organic milk are substitutes. Cow's milk categories and each of the PBMA categories are substitutes. The respective dairy and non-dairy milk products are necessities.

Key words: Circana time-series data, dairy milk products, Exact Affine Stone Index demand systems model, plant-based milk alternatives

Introduction

Investigations pertaining to the demand for fluid milk have become increasingly complex over the past decade largely attributed to concerns about health and nutrition, animal welfare, and environmental sustainability as well as competition from plant-based milk alternatives (PBMA), bottled water, refrigerated and shelf-stable juices and drinks, and sports drinks (Stewart, Kuchler, and Hahn, 2021). The dairy industry has developed specific milk categories, including but not limited to lactose-free milk for those diagnosed as being lactose intolerant, reduced fat, low-fat, or fat-free milk for those concerned about weight gain, and health-enhanced milk for those concerned about health and nutrition in general (e.g., fairlife[1]). While overall fluid milk consumption has been declining, lactose-free milk volume sales have skyrocketed by slightly more than 40% from 215.7 million gallons in 2020 to 304.4 million gallons in 2024, an annual compound growth rate of 7.13%. Further, organic white milk sales have grown from 271 million gallons in 2015 to 343 million gallons in 2024, a rise of roughly 25% over the past ten years (U.S. Department of Agriculture, 2024). This rise in organic white milk sales over the past ten years corresponds to an annual compound growth rate of 4.68%. The demand for organic milk is on the rise, driven not only by health-conscious consumers but also by continued emphasis on sustainable agriculture.

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[1] The brand, owned by the Coca-Cola Company, first appeared in Minnesota, launched in February 2014. The brand is known as ultra-filtered milk that contains more protein and less sugar than conventional milk, https://fairlife.com/ .

Meanwhile, the non-dairy industry also has been promoting various PBMAs, with almond, oat, coconut, and soy as the top four (UCDAVIS Innovation Institute for Food and Health, 2022). The market penetration of PBMA had been on the rise until recently. PBMA consumption fell from 6.9 gallons per buyer in 2021 to 6.4 gallons per buyer in 2024. The number of households buying PBMA fell from 52.3% in 2021 to 48.6% in 2024 (Adams, 2025).

The main objective of the current study is to empirically explore demand interrelationships among cow's milk and PBMA categories in the United States making use of advancements in consumer demand analysis. The specific objectives are twofold: (1) to estimate an Exact-Affine Stone Index (EASI) demand model allowing for flexible Engel curve shapes and correcting for total expenditure and price endogeneity, as well as accounting for serial correlation; and (2) to estimate uncompensated and compensated own-price and cross-price elasticities, along with expenditure and income elasticities of demand for a disaggregated set of cow's milk products and PBMA.

While previous studies have contributed to our understanding of milk demand, to date, no study has centered attention on the demand relationships among disaggregated dairy milk categories and PBMA categories on this level of detail. Therefore, this study expands on previous research by offering several unique contributions to the extant literature. First, in contrast to most prior studies, except for Ghazaryan et al. (2023), this research employs the Exact Affine Stone Index (EASI) demand model, which retains the appealing features of widely used demand systems while enhancing its methodological strengths. Specifically, the EASI demand systems model accounts for unobserved consumer heterogeneity and allows for flexible Engel curve shapes. Considering unobserved consumer heterogeneity is crucial, as it explains a significant portion of consumer demand variation (Pendakur, 2009). Similarly, allowing for flexible Engel curves ensures a more accurate assessment of income effects (Lewbel and Pendakur, 2009).

Second, this study utilizes weekly scanner data from January 2017 to August 2023 associated with price and quantity information on an extensive set of PBMA categories (almond milk, cashew milk, coconut milk, oat milk, rice milk, soy milk) and cow's milk products (lactose-free milk, traditional white milk, and organic milk). No previous study has focused on this level of disaggregation among PBMA and cow's milk products. Third, both expenditure and price endogeneity are corrected in the demand model, with the latter being remedied via a unique instrument of total points of distribution, which, to the best of our knowledge, has not been used in prior studies. In general, ignoring expenditure and price endogeneity can result in inconsistent parameter estimates, which, in turn, can lead to inaccurate demand and policy implications (Hovhannisyan and Bozic, 2017; Hovhannisyan et al., 2020).

The findings from this analysis provide valuable insights into demand patterns for different types of dairy and non-dairy milk products in the United States, offering useful information to various stakeholders. For instance, producers and retailers can leverage information on price elasticities of demand to develop pricing strategies that maximize revenue, optimize input procurement, and manage inventory efficiently. From a competitive intelligence standpoint, we delineate intra- and inter-cross-price elasticities of demand among the respective cow's milk and PBMA categories. That is to say, among cow's milk products, we identify the chief competitior to traditional white milk, organic milk, and lactose-free milk within this category by examining the Hicksian intra-cross-price elasticities. Similarly, we identify the chief competitor to each of these cow's milk products by estimating the Hicksian inter-cross-price elasticities among the PBMA categories. We conduct a similar analysis for the respective disaggregated PBMA products.

In the next section, we provide a perspective of our study through a review of the literature. In the subsequent section, we delineate the details of the EASI model and discuss issues regarding serial correlation and endogeneity. In the ensuing section, we discuss the data and the construction of variables, followed by the presentation and discussion of the estimation results. In the final section, we provide a summary, conclusions, and recommendations for future research.

Literature Review

Prior studies have been instrumental in shedding light on the structure of milk demand in the United States. In particular, based on a linear hedonic Barten synthetic demand systems model using Nielsen Homescan consumer panel data during the period 2004-2015, Yang and Dharmasena (2021) estimated uncompensated own-price elasticities to be -0.42 for 2% milk, -0.33 for 1% milk, -0.28 for fat-free milk, and -0.22 for whole milk. Estimated own-price elastcities for PBMA products were -0.13 for almond, -0.50 for soy, and -0.10 for rice milk alternatives. The demands for the respective cow's milk products and the PBMA products were inelastic. Based on compensated intra-cross-price elasticities, almond, soy, and rice PBMA products were complements, but 2% milk, 1% milk, fat-free milk, and whole milk were substitutes among dairy products. Based on compensated inter-cross-price elasticities, almond and 1% milk were complements; soy and each of the cow's milk products were substitutes; rice and 1% milk as well as rice and whole milk were complements.

Ghazaryan et al. (2023), through the use of weekly scanner data from 2012 to 2017 and the estimation of a linear-approximate EASI demand system, focused on skim, reduced fat, and whole milk as well as almond, soy, and other non-dairy categories. They estimated uncompensated own-price elasticities to be -1.30 for skim milk, -1.67 for reduced fat milk, and -1.45 for whole milk. The estimated uncompensated own-price elasticities for soy, almond, and other non-dairy milk alternatives were -1.30, -0.85, and -1.63, respectively. Ghazaryan et al. (2023) substantiated that reduced fat milk and skim milk as well as reduced fat milk and whole milk were substitutes but that skim milk and whole fat milk were complements. Further, soy and almond milk alternatives were substitutes, but almond and other non-dairy milk alternatives as well as soy and other non-dairy milk alternatives were complements. Almond milk was a substitute for skim, reduced fat, and whole milk. Soy milk was a substitute for skim and whole milk, but soy was a complement to reduced fat milk. Other non-dairy milk alternatives were a substitute for skim and reduced fat milk, but other non-dairy milk alternatives were a complement to whole milk.

Lee and Sumner (2023) estimated a random coefficient logit model using Nielsen's Homescan Consumer Panel data and Retail Measurement Services data to analyze the demand interrelationship pattern between liquid retail cow's milk products and plant-based milk products. The empirical results suggested an inelastic demand for conventional milk (-0.686) and an elastic demand for organic milk (-2.452) and lactose-free milk (-3.152). Also, plant-based milk alternatives were found to be more substitutable to organic milk and lactose-free milk than to conventional milk.

In addition, using the Almost Ideal Demand System (AIDS) model, Son and Lusk (2023) estimated the uncompensated own-price elasticity for traditional white milk to be -0.95 and for lactose-free milk to be -1.39. Further, Son and Lusk (2023) reported own-price elasticities for almond, oat, coconut, and soy plant-based milk alternatives to be -1.99, -0.57, -1.13, and -0.26, respectively. Regular dairy milk and lactose were gross substitutes. Almond and soy as well as oat and coconut were gross substitutes. On the other hand, almond and oat, oat and soy, and coconut and soy were gross complements. Finally, almond and coconut were independent goods.

Capps and Wang (2024) utilized the Quadratic AIDS (QUAIDS) model (Banks et al, (1997)) based on the Nielsen Consumer Panel over calendar years 2018 to 2020 to estimate demand interrelationships among five product categories: traditional white milk, traditional flavored milk, lactose-free milk, organic milk, and the aggregate of plant-based milk alternatives. The uncompensated own-price elasticities for dairy milk products were indicative of elastic demands, ranging from -1.05 (traditional white milk) to -1.23 (organic milk). The own-price elasticity for the aggregate category PBMA was estimated to be -0.87, indicative of inelastic demand. Based on compensated cross-price elasticities, organic milk and lactose-free milk as well as PBMA and traditional flavored milk were complements. PBMA and lactose-free milk were independent goods. The remaining compensated cross-price elasticities were positive and statistically significant, indicative of substitutes in agreement with previous findings. Lactose-free milk was the best substitute or principal competitor for traditional white milk and vice versa. Lactose-free milk and traditional white milk were the best substitutes for traditional flavored milk. Traditional white milk was the best substitute for organic milk and for PBMA.

The own-price elasticity for conventional white milk varied from -0.11 to -1.56 (Davis et al., 2012; Dong, Chung, and Kaiser, 2004; Hovhannisyan and Gould, 2012; Li et al., 2018). The own-price elasticity for organic milk ranged from -0.38 to -2.46 (Alviola and Capps, 2010; Chen et al., 2018; Dhar and Foltz, 2005; Gulseven and Wohlgenant, 2017; Li et al., 2018). Gulseven and Wohlgenant (2017) estimated the own-price elasticity of lactose-free milk to be -0.20. These studies are relatively dated and as such do not deal with more recent time periods.

In sum, based on this literature review, no previous study has analyzed demand interrelationships among traditional white milk, lactose-free milk, and organic milk together with almond, oat, coconut, cashew, rice, and soy plant-based milk alternatives.

Model

Linear Approximate EASI (LA-EASI) Demand Specification

Our analysis relies on estimating the EASI demand model. The EASI model enhances previous demand system models by incorporating methodological improvements reflected in allowing for unobserved consumer heterogeneity and flexible Engel curve shapes, with the latter being important for evaluating income effects (Pendakur, 2009; Lewbel and Pendakur, 2009). Given the time-series nature of our data, potential serial correlation in the error terms needs to be accounted for. To that end, based on the study by Berndt and Savin (1975), we employ a first-order autoregressive correction procedure applied to the EASI demand model as follows:

(1) $$w_{it} = \rho_1 w_{it-1} + \alpha_{i0} + \sum_{j=1}^{N} \gamma_{ij} \ln p_{jt} + \sum_{l=1}^{L} \beta_{il} y_{it}^{l} - \rho_1 \left(\alpha_{i0} + \sum_{j=1}^{N} \gamma_{ij} \ln p_{jt-1} + \sum_{l=1}^{L} \beta_{il} y_{it-1}^{l} \right) + \varepsilon_{it}, \text{ for any } i = 1, \ldots, N;\ t = 1, \ldots, T,$$

where w_{it} stands for the budget share of product i in period t, p_{jt} stands for the price of product j in period t, y_{it} stands for real expenditures on milk products in period t, N and T represent the number of products and the number of time periods, respectively, L represents the highest order of polynomial in expenditures which is determined empirically, ρ_1 is the serial correlation coefficient, α_{i0}, γ_{ij}, and β_{il} are the parameters to be estimated, and ε_{it} represents the error term.

The budget share equations in the EASI demand model in (1) are estimated with the classical theoretical restrictions of adding-up, homogeneity, and symmetry imposed on the parameters as follows:

(2) $$\sum_i \alpha_{i0} = 1, \sum_i \gamma_{ij} = 0, \sum_i \beta_{il} = 0, \text{ for any j=1…N, and } \gamma_{ij} = \gamma_{ji} \text{ for any j≠i.}$$

We adopt a linear approximate EASI demand model (LA-EASI) introduced by Lewbel and Pendakur (2009). With x_t representing total nominal expenditures, y_t is specified as Stone price-deflated real expenditures as follows:

(3) $$y_t = \ln(x_t) - \sum_j^N w_{jt} \ln(p_{jt}).$$

This study employs the LA-EASI demand model because, in addition to having the desirable characteristics of the AIDS model by Deaton and Muellbauer (1980), it also accounts for unobserved consumer heterogeneity and allows for flexible Engel curve shapes (Pendakur, 2009; Lewbel and Pendakur, 2009). Notably, in nonlinear versions of the EASI model, y_t represents an affine transformation of Stone price-deflated real expenditures. The EASI model ensures that the Stone price serves as an exact deflator of real expenditures, unlike the linear approximate AIDS model, where it only approximates the true expenditure deflator (Zhen et al., 2013). Additionally, studies have shown that estimated parameters from the LA-EASI model closely align with those from its nonlinear version (Lewbel and Pendakur, 2009).

Based on the parameter estimates from the LA-EASI model, own-price and cross-price elasticities of demand as well as expenditure elasticities are calculated making use of the formulas provided by Zhen et al. (2013). Particularly, the compensated (Hicksian) price elasticities (e_{ij}^{C}) can be computed as follows:

(4) $$e_{ij}^{C} = \frac{\gamma_{ij}}{w_i} + w_j - \delta_{ij}, \text{ for any i, j=1,…,N,}$$

where δ_{ij} is the Kronecker delta, assuming the value of 1 if $i=j$, and 0 otherwise. The expenditure elasticity is calculated as follows:

(5) $$E = \left(diag(W)\right)^{-1}[(I_N + BP')^{-1}B] + 1_N,$$

where E represents the (N x 1) vector of expenditure elasticities, W represents the (N x 1) vector of budget shares, I_N represents a (N x 9) identity matrix, B represents an (N x 1) vector with the i^{th} element given by $\sum_{l=1}^{L} \beta_{il} l y^{l-1}$, P is the (N x 1) vector of logarithmic prices, and 1_N is the (N x 1) vector of ones. The uncompensated (Marshallian) price elasticities (e_{ij}^{U}) can be calculated utilizing the Slutsky as follows:

(6) $$e_{ij}^{U} = e_{ij}^{C} - e_i w_j,$$

where e_{ij}^{C} and e_i are the corresponding compensated price and expenditure elasticity, respectively.

Correcting for Total Expenditure and Price Endogeneity

Before the estimation of the LA-EASI demand model, it is essential to correct endogeneity issues in real expenditures and prices. Specifically, endogeneity in real expenditures may arise due to a potential simultaneity bias in the LA-EASI model's budget share equations. This bias occurs because real expenditures appear as an explanatory variable on the right-hand side, while simultaneously being used in the construction of budget shares on the left-hand side. Thus, following the approach of Dhar, Chavas, and Gould (2003), this endogeneity issue is resolved by incorporating the following reduced-form real expenditure equation into the LA-EASI demand model:

(7) $$y_t = \theta_0 + \theta_1 ln\_pc\_rl\_dispinc_t + \nu_t,$$

where $ln\_pc\_rl\_dispinc_t$ is a logarithmic transformation of per capita real disposable income used as an instrument for real expenditures, θ_0 and θ_1 are parameters to be estimated, and ν_t is the error term. Importantly, income elasticities for all milk types can be calculated by multiplying θ_1 by corresponding expenditure elasticity (see Bakhtavoryan et al. (2021) for the derivation of the income elasticity).

The price endogeneity arises from supply and demand simultaneity, meaning that price and quantity are jointly determined by the interaction of demand and supply. To correct for this price endogeneity, we use total points of distribution of milk types as instrument for endogenous prices. The total points of distribution of a milk type refers to the number of retail locations or distribution points where a milk type is available for purchase. Using total points of distribution as an instrument for milk prices can be explained as a supply shifter because of its direct impact on supply availability. In other words, an increase in total points of distribution of a milk type or PBMA type implies that the relevant product is being distributed to more retail locations. This situation generally represents an expansion in supply, either due to increased production, better logistics, or improved retail partnerships. As a result, a greater supply at more locations can put downward pressure on prices.

Additionally, while total points of distribution may be correlated with the price of a milk type or PBMA type, it primarily reflects business decisions related to supply chain expansion, making it a valid instrument that shifts supply without being directly determined by consumer demand. As such, the LA-EASI demand model is appended with a set of reduced-form price equations where the endogenous cow's milk and PBMA prices (p_{it}) are modeled as a function of logarithmic transformation of total points of distribution (tpd_{it}) as follows:

$$p_{it} = \omega_0 + \delta tpd_{it} + \psi_{it}. \tag{8}$$

The DWH test, developed by Durbin (1954), Wu (1973), and Hausman (1978), is used to assess expenditure and price endogeneity. Details of the test can be found in Dhar, Chavas, and Gould (2003). The DWH test examines whether there are statistically significant differences in parameter estimates for variables suspected to be endogenous. These estimates are derived from two demand models - one that does not control for potential endogeneity and another that explicitly accounts for it. The null hypothesis assumes exogeneity, and the test statistic follows a $\chi^2(g)$ distribution, where g represents the number of potentially endogenous variables.

Data

The data underlying this study come from Circana (formerly Information Resources, Inc. (IRI)), and were procured in a contract with the International Dairy Foods Association. These data constitute a heterogeneous collection of sales (dollars), volume sold (gallons), and prices (dollars per gallon) of different types of milk products and PBMAs from various types of retail stores, including grocery, drug, mass merchandisers, club stores, dollar stores, and military commissaries across the United States. Essentially, this dataset provides a comprehensive view across multiple retail channels rather than just one specific outlet for the United States. Consequently, we are in position to analyze market trends across a wide range of retail environments within the United States.

The time-series data range from the week ending on January 8, 2017, to the week ending on August 13, 2023, for a total of 345 weekly observations. The information provided by the data pertains to weekly quantity sold in gallons and prices in $/gallon of nine product types including almond, cashew, coconut, oat, rice, and soy plant-based milk alternatives as well as lactose-free milk, traditional white milk, and organic milk. The quantity sold for every milk type is expressed on per capita basis using population acquired from the Federal Reserve Bank of St. Louis (2025). Also, real prices are used in the present analysis, and they are obtained by deflating nominal prices utilizing the Consumer Price Index reported by the Federal Reserve Bank of St. Louis (2025) with the year 2015 being the base period.

The descriptive statistics of per capita quantities, prices, and budget shares concerning the nine product types are depicted in Table 1. According to the results in Table 1, the average per capita quantities of almond milk (0.0138 gallons), cashew milk (0.0003 gallons), coconut milk (0.0011 gallons), oat milk (0.0015 gallons), rice milk (0.0002 gallons), soy milk (0.0018 gallons), lactose-free milk (0.0106 gallons), traditional white milk (0.1543 gallons), and organic milk (0.0116 gallons) imply that traditional white milk is the most popular milk type and rice milk is the least popular milk type. Per real prices, coconut milk and oat milk emerge as the highest-priced product types with the respective average real prices of $10.98 and $9.08 per gallon, while traditional white milk is the cheapest milk type with the corresponding average real price of $2.98 per gallon. Based on the average budget shares over the study period, the dominant category is traditional white milk with a budget share of about 61.89%, followed by organic milk (11.66%), lactose free milk (10.66%), and almond milk (10.51%). The budget shares of the remaining categories are less than 2% each. The respective cow's milk products in this analysis not only

Table 1. Descriptive Statistics of Quantities, Prices, and Budget Shares of Milk Types (*N* = 345)

Variables	Mean	Standard Deviation
Per capita quantities, (gallons)		
Almond milk	0.0138	0.0017
Cashew milk	0.0003	0.0001
Coconut milk	0.0011	0.0001
Oat milk	0.0015	0.0014
Rice milk	0.0002	0.0000
Soy milk	0.0018	0.0003
Lactose-free milk	0.0106	0.0019
Traditional white milk	0.1543	0.0149
Organic milk	0.0116	0.0008
Real prices ($/gallon)		
Almond milk	5.6855	0.3038
Cashew milk	6.5626	0.5654
Coconut milk	10.9762	0.9388
Oat milk	9.0822	1.4259
Rice milk	7.9101	0.2134
Soy milk	6.4810	0.3311
Lactose-free milk	7.4369	0.2155
Traditional white milk	2.9812	0.1456
Organic milk	7.4268	0.2074
Budget shares (%)		
Almond milk	10.5148	0.0093
Cashew milk	0.2373	0.0008
Coconut milk	1.6039	0.0019
Oat milk	1.6724	0.0150
Rice milk	0.2159	0.0005
Soy milk	1.5544	0.0031
Lactose-free milk	10.6561	0.0174
Traditional white milk	61.8899	0.0300
Organic milk	11.6553	0.0054

Note: Researcher(s)' own analyses calculated based on data from Circana procured in a contract with the International Dairy Foods Association.

have the highest budget shares but also, they account for roughly 84% of the total expenditure in the demand system. The key PBMA categories in terms of budget share are almond, oat, coconut, and soy in that order.

Estimation Results

The linear approximate EASI demand system for nine dairy and non-dairy products along with the reduced-form expenditure and price equations is estimated via a Full Information Maximum Likelihood (FIML) approach using the MODEL procedure in the SAS 9.4 statistical software (SAS 9.4, 2013). The FIML procedure allows for contemporaneous correlation across the

Table 2. Summary of the LA-EASI Demand Model Diagnostic Tests

Hypothesis tests for model specification	χ^2 statistic	p-value
Quadratic vs. linear Engel curves	235.32	<0.0001
Cubic vs. quadratic Engel curves	126.6	<0.0001
Quartic vs. cubic Engel curves	84.08	<0.0001
Quintic vs. quartic Engel curves	23.4	0.0030
Sextic vs. quintic Engel curves	40.86	<0.0001
Septic vs. sextic Engel curves	15.32	0.0530
Durbin-Wu-Hausman test of price and expenditure exogeneity	90.57	<0.0001

Note: Researcher(s)' own analyses calculated based on data from Circana procured in a contract with the International Dairy Foods Association.

unobserved milk demand determinants, while also correcting for expenditure and price endogeneity (Hayashi 2000). We implicitly assume that the considered nine products are weakly separable from other food and nonfood products. The budget share equation for organic milk is excluded from the estimation to avoid the singularity of the variance-covariance matrix of error terms, which arises because budget shares sum to one in the LA-EASI demand model. The parameters of the excluded budget share equation are then recovered using the parametric constraints of adding-up, homogeneity, and symmetry.

To ascertain the proper degree of real expenditure polynomial function, the LA-EASI demand model is initially estimated with the degree set at one (i.e., linear demand model). Then, the degree is incrementally raised, and the likelihood ratio test is conducted to evaluate the superiority of more general models. The χ^2 test statistic and its associated *p*-values from the likelihood ratio tests for various degrees of real expenditures are depicted in Table 2.

According to the results in Table 2, the sextic (the 6th degree) LA-EASI demand model emerges superior to the rest of the model specifications (the *p*-value of the χ^2 statistic between the septic and the sextic degrees is 0.053, leading us to fail to reject the null hypothesis of no difference between the two specifications). Therefore, the rest of the analysis is based on the results obtained from the estimation of the 6th degree LA-EASI demand model. In Ghazaryan et al. (2023), the LA-EASI specification with a fifth polynomial in real expenditure was sufficient to capture the curvature of the Engel curves.

Based on the χ^2 statistic of 90.57 along with the associated *p*-value of virtually 0 from the DWH test, the null hypothesis of exogeneity of total expenditure and prices is rejected, thereby empirically supporting our correction for endogeneity. Even though the empirical results from the reduced form total expenditure and price equations are not reported for the purpose of brevity, nonetheless, they are readily available upon request. The vast majority of parameter estimates associated with the instruments are statistically significant and possess signs that are in line with economic theory.

The parameter estimates, their standard errors, goodness-of-fit (R^2), and the Durbin-Watson statistics from the LA-EASI demand model are reported in Table 3. The Durbin-Watson statistics of around two for the nine estimated budget share equations along with the statistically significant serial correlation coefficient of ρ_1 suggest that the serial correlation is properly accounted for in the LA-EASI demand model. The R^2s vary dramatically from 0.0617 (almond milk) to 0.9899 (oat milk).

While the parameter estimates do not offer a direct intuitive economic interpretation, they are used in the calculation of demand elasticities. Uncompensated (Marshallian) own-price, cross-price elasticities, expenditure, and income elasticities of demand calculated at the sample means are reported in Table 4. Consistent with the law of demand, all the uncompensated own-price elasticities emerge as negative and statistically significant. Per the values of uncompensated

Table 3. Parameter Estimates, Standard Errors, Goodness-of-Fit (R^2), and Durbin-Watson Statistics from the LA-EASI Demand Model

Parameters	Almond milk	Cashew milk	Coconut milk	Oat milk	Rice milk	Soy milk	Lactose-free milk	Traditional white milk	Organic milk
Intercept (α_{i0})	0.0679	0.0038	-0.0038	0.0360*	0.0015	0.0098	0.1422***	0.6333	0.1094
	(0.7116)	(0.0066)	(0.0415)	(0.0194)	(0.0045)	(0.0130)	(0.0495)	(0.6524)	(0.1079)
Almond milk price (γ_{1i})	-0.3017	-0.001	0.0029	-0.0068*	-0.0019	-0.0018	0.0062**	0.2982	0.0060
	(0.1965)	(0.0019)	(0.0041)	(0.0038)	(0.0014)	(0.0040)	(0.0031)	(0.1969)	(0.0059)
Cashew milk price (γ_{2i})		-0.0014**	0.0005*	-0.0002	-0.00004	-0.0002	0.0001	0.0021	0.0002
		(0.0006)	(0.0003)	(0.0003)	(0.0001)	(0.0003)	(0.0001)	(0.0021)	(0.0003)
Coconut milk price (γ_{3i})			0.0107***	-0.00002	-0.0002*	-0.0008*	0.0006	-0.0119*	-0.0019
			(0.0032)	(0.0009)	(0.0001)	(0.0005)	(0.0005)	(0.0067)	(0.0012)
Oat milk price (γ_{4i})				-0.0020	-0.00003	-0.0006	0.0008	0.0066	0.0023
				0.0014	(0.0001)	(0.0006)	(0.0008)	(0.0054)	(0.0018)
Rice milk price (γ_{5i})					0.0004***	-0.00004	0.0001	0.0014	0.0004*
					(0.0001)	(0.0001)	(0.0001)	(0.0014)	(0.0002)
Soy milk price (γ_{6i})						0.0041***	0.0001	-0.0029	0.0021
						(0.0015)	(0.0003)	(0.0043)	(0.0012)
Lactose-free milk price (γ_{7i})							-0.0130***	0.0028	0.0023*
							(0.0034)	(0.0049)	(0.0014)
Traditional white milk price (γ_{8i})								-0.2526	-0.0438**
								(0.1965)	(0.0219)
Organic milk price (γ_{9i})									0.0324*
									(0.0168)
Real expenditure (β_{i1})	-0.0010	-0.0001*	-0.0003**	0.00004	-0.00002	-0.0003**	-0.0005	0.0039**	-0.0016***
	(0.0010)	(0.00004)	(0.0001)	(0.0003)	(0.00002)	(0.0001)	(0.0007)	(0.0019)	(0.0005)
Real expenditure (β_{i2})	0.0007	0.00001	0.0001	0.0001	5.359E-6	0.00003	0.00003	-0.0011	0.0001
	(0.0004)	(0.00002)	(0.0001)	(0.0002)	(0.00001)	(0.0001)	(0.0003)	(0.0008)	(0.0003)
Real expenditure (β_{i3})	-0.0004*	-0.00001	-0.00003	-0.0001	-8.94E-6*	-0.00002	-0.0002	0.0008	-0.00002
	(0.0002)	(0.00001)	(0.00005)	(0.0001)	(5.273E-6)	(0.00003)	(0.0002)	(0.0005)	(0.0001)
Real expenditure (β_{i4})	-0.0001	-1.59E-6	-0.00004	3.82E-6	-2.98E-7	-1.25E-6	0.00004	0.0001	0.00003
	(0.0001)	(5.67E-6)	(0.00003)	(0.00005)	(4.056E-6)	(0.00002)	(0.0001)	(0.0003)	(0.0001)
Real expenditure (β_{i5})	0.0001	9.945E-7	0.00002	1.803E-6	9.029E-7	1.329E-6	-6.38E-7	-0.0001	-0.00002
	(0.00004)	(2.31E-6)	(0.00001)	(0.00002)	(1.346E-6)	(7.533E-6)	(0.00004)	(0.0001)	(0.00003)
Real expenditure (β_{i6})	-5.05E-6	-8.41E-8	-1.2E-6	-1.64E-7	-9.38E-8	-1.22E-7	-1.66E-7	4.843E-6	2.04E-6
	(3.891E-6)	(2.04E-7)	(9.854E-7)	(1.481E-6)	(1.102E-7)	(6.271E-7)	(3.217E-6)	(8.312E-6)	(2.993E-6)
R^2	0.0617	0.4354	0.3944	0.9899	0.4887	0.8956	0.9654	0.2560	0.2094
Durbin-Watson	1.9458	2.2596	2.1967	2.1377	2.0379	2.3943	2.2370	1.9800	2.2782
ρ_1	0.9943***								
	(0.0025)								

Notes: Values in parentheses are the standard errors. Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level, respectively. ρ_1 is the serial correlation coefficient. Initially, the LA-EASI model was estimated with dummy variables accounting for Covid-19 pandemic and seasonality. However, these dummy variables were taken out from the final estimation due to their statistical insignificance. Researcher(s)' own analyses calculated based on data from Circana procured in a contract with the International Dairy Foods Association.

Table 4. Uncompensated (Marshallian) Price, Expenditure, and Income Elasticity Estimates and Associated Standard Errors from the LA-EASI Demand Model

Milk types	Almond milk	Cashew milk	Coconut milk	Oat milk	Rice milk	Soy milk	Lactose-free milk	Traditional white milk	Organic milk	Expenditure	Income
Almond milk	-3.8682**	-0.0095	0.0276	-0.0647*	-0.0183	-0.0173	0.0599**	2.8421	0.0581	0.9902**	0.2442**
	(1.8687)	(0.0179)	(0.0394)	(0.0361)	(0.0132)	(0.0384)	(0.0292)	(1.8727)	(0.0562)	(0.1113)	(0.1189)
Cashew milk	-0.4162	-1.5997***	0.2137*	-0.0962	-0.0173	-0.0866	0.0339	0.9131	0.0891	0.9663**	0.2383**
	(0.7943)	(0.2574)	(0.1212)	(0.1132)	(0.0304)	(0.1228)	(0.0559)	(0.9104)	(0.1466)	(0.1089)	(0.1160)
Coconut milk	0.1822	0.0316*	-0.3324*	-0.0011	-0.0094*	-0.0493*	0.0424	-0.7262*	-0.1161	0.9782**	0.2413**
	(0.2581)	(0.0179)	(0.1994)	(0.0535)	(0.0057)	(0.0294)	(0.0331)	(0.4190)	(0.0755)	(0.1041)	(0.1174)
Oat milk	-0.4082*	-0.0137	-0.0014	-1.1191***	-0.0021	-0.0348	0.04604	0.3954	0.1358	1.0021**	0.2472**
	(0.2268)	(0.0161)	(0.0513)	(0.0833)	(0.0067)	(0.0337)	(0.0505)	(0.3253)	(0.1069)	(0.0987)	(0.1203)
Rice milk	-0.8927	-0.0191	-0.0697*	-0.0160	-0.8208***	-0.0174	0.0458	0.6328	0.1663*	0.9907**	0.2444**
	(0.6411)	(0.0334)	(0.0421)	(0.0516)	(0.0626)	(0.0531)	(0.0343)	(0.6400)	(0.0989)	(0.1112)	(0.1189)
Soy milk	-0.1158	-0.0133	-0.0509*	-0.0371	-0.0024	-0.7367***	0.0081	-0.1715	0.1401*	0.9794**	0.2416**
	(0.2598)	(0.0187)	(0.0303)	(0.0362)	(0.0074)	(0.0946)	(0.0219)	(0.2757)	(0.0784)	(0.1043)	(0.1176)
Lactose-free milk	0.0586**	0.0007	0.0061	0.0073	0.0009	0.0009	-1.1214***	0.0292	0.0224*	0.9952**	0.2455**
	(0.0288)	(0.0013)	(0.0050)	(0.0079)	(0.0007)	(0.0032)	(0.0323)	(0.0460)	(0.0132)	(0.1201)	(0.1195)
Traditional white milk	0.4812	0.0034	-0.0193*	0.0106	0.0022	-0.0047	0.0038	-1.4120***	-0.0715**	1.0063**	0.2482**
	(0.3182)	(0.0035)	(0.0109)	(0.0088)	(0.0022)	(0.0069)	(0.0079)	(0.3174)	(0.0354)	(0.1113)	(0.1208)
Organic milk	0.0529	0.0018	-0.0161	0.0198	0.0031*	0.0186*	0.0215*	-0.3675*	-0.7201***	0.9862**	0.2432**
	(0.0507)	(0.0030)	(0.0104)	(0.0153)	(0.0018)	(0.0105)	(0.0121)	(0.1882)	(0.1440)	(0.0923)	(0.1184)

Notes: Elasticities are calculated at the sample means. Values in the parentheses are the standard errors. Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level, respectively. Researcher(s)' own analyses calculated based on data from Circana procured in a contract with the International Dairy Foods Association.

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own-price demand elasticities, the demands for several non-dairy products, namely almond (-3.87), cashew (-1.60), and oat (-1.12), as well as for dairy products, specifically, lactose-free milk (-1.12) and traditional white milk (-1.41) are elastic, while the demands for coconut (-0.33), rice (-0.82), and soy (-0.74) plant-based milk alternatives as well as organic milk (-0.72) are inelastic. These estimated own-price elasticities are considerably larger than those reported by Yang and Dharmasena (2021) for almond, soy, and rice. Our estimated own-price elasticity for almond milk is also much higher than -1.30 as reported by Ghazaryan et al. (2023) and -1.99 as reported by Son and Lusk (2023). However, our estimated own-price elasticity for soy milk is lower than -0.85 as reported by Ghazaryan et al. (2023) but is higher than -0.26 as reported by Son and Lusk (2023). Additionally, our estimated own-price elasticities for oat, coconut, traditional white milk, and lactose-free milk are notably different from -0.57, -1.13, -0,95, and -1.39 as reported by Son and Lusk (2023). The estimated own-price elasticities for traditional white milk and lactose-free milk align with Capps and Wang (2024). But the estimated own-price elasticity for organic milk is much lower than -1,23 as reported by Capps and Wang (2024). Suffice it to say that conditional on our set of disaggregated cow's milk and PBMA categories along with the use of the LA-EASI demand systems model as well as more current data, we provide evidence of notable differences in estimated own-price elasticities as reported by the extant literature.

All the calculated expenditure elasticities are positive and statistically significant and are close to unity in value, with the most expenditure elastic product type being traditional white milk (1.01) and the least expenditure elastic milk type being cashew milk (0.97). These results compare favorably with those from Capps and Wang (2024) and Ghazaryan et al. (2023). Finally, all the income elasticity estimates are positive and statistically significant ranging from 0.24 for cashew milk to 0.25 for traditional white milk. All the income elasticities are less than one in value indicating that milk types are not only normal goods but also necessities.

The uncompensated cross-price elasticities reflect both the substitution effect and the income effect and thereby do not provide viable information about pure substitutability relationships between milk types. The substitutability analysis is done in terms of compensated cross-price elasticities that are net of income effects. In Table 5, we report compensated (Hicksian) price elasticities of demand calculated at the sample mean values from the LA-EASI demand model. Consistent with consumer demand theory, all the compensated own-price elasticity estimates are negative and statistically significant. Most of the statistically significant compensated cross-price elasticities are positive and reveal a net substitutability relationship among types of dairy and non-dairy milk. Concerning intra-cross-price elasticities among the PBMA categories, almond and oat are complements, while cashew and coconut are substitutes. Aside from these findings, no substitutability or complementarity among PBMAs is evident. Hence, predominantly, PBMAs are virtually independent goods. This finding is at odds with Yang and Dharmasena (2021), Ghazaryan et al. (2023), and Son and Lusk (2023) who presented evidence of substitutability and/or complementarity among plant-based milk alternatives.

Concerning intra-cross-price elasticities among the cow's milk categories, lactose-free milk, traditional white milk, and organic milk are substitutes. Concerning inter-cross-price elasticities, the respective cow's milk categories and each of the PBMA categories are substitutes. This finding aligns with Ghazaryan et al. (2023). The only exceptions are with respect to coconut and traditional white milk as well as with respect to coconut and organic milk.

The chief competitor to almond, cashew, oat, rice, and soy plant-based milk alternatives is traditional white milk. In agreement with Capps and Wang (2024), the principal competitor to lactose-free milk and organic milk also is traditional white milk. The chief competitor to traditional white milk and to coconut milk is almond milk.

Table 5. Compensated (Hicksian) Price Elasticity Estimates and Associated Standard Errors from the LA-EASI Demand Model

Milk types	Almond milk	Cashew milk	Coconut milk	Oat milk	Rice milk	Soy milk	Lactose-free milk	Traditional white milk	Organic milk
Almond milk	-3.7641**	-0.0071	0.0435	-0.0482*	-0.0162	-0.0018	0.1654***	3.4550*	0.1735***
	(1.8687)	(0.0179)	(0.0394)	(0.0361)	(0.0132)	(0.0384)	(0.0292)	(1.8727)	(0.0562)
Cashew milk	-0.3146	-1.5974***	0.2292*	-0.0800	-0.0152	-0.0716	0.1369**	1.5111*	0.2017*
	(0.7943)	(0.2574)	(0.1212)	(0.1132)	(0.0304)	(0.1228)	(0.0559)	(0.9104)	(0.1466)
Coconut milk	0.2851	0.0339*	-0.3167*	0.0153	-0.0072	-0.0341	0.1467***	-0.1208	-0.0021
	(0.2581)	(0.0179)	(0.1994)	(0.0535)	(0.0057)	(0.0294)	(0.0331)	(0.4190)	(0.0755)
Oat milk	-0.3028*	-0.0114	0.0146	-1.1023***	0.0001	-0.0192	0.1528***	1.0156***	0.2525**
	(0.2268)	(0.0161)	(0.0513)	(0.0833)	(0.0066)	(0.0337)	(0.0505)	(0.3253)	(0.1069)
Rice milk	-0.7885	-0.0167	-0.0538	0.0006	-0.8187***	-0.0020	0.1514***	1.2459**	0.2819***
	(0.6411)	(0.0334)	(0.0421)	(0.0516)	(0.0626)	(0.0531)	(0.0343)	(0.6400)	(0.0989)
Soy milk	-0.0128	-0.0109	-0.0352	-0.0207	-0.0003	-0.7215***	0.1125***	0.4347*	0.2542***
	(0.2598)	(0.0187)	(0.0303)	(0.0362)	(0.0074)	(0.0946)	(0.0219)	(0.2757)	(0.0784)
Lactose-free milk	0.1632***	0.0030**	0.0221***	0.0240***	0.0031***	0.0164***	-1.0153***	0.6451***	0.1384***
	(0.0288)	(0.0013)	(0.0050)	(0.0079)	(0.0007)	(0.0031)	(0.0323)	(0.0460)	(0.0132)
Traditional white milk	0.5870*	0.0058*	-0.0031	0.0274***	0.0043*	0.0109*	0.1111***	-0.7892**	0.0457*
	(0.3182)	(0.0035)	(0.0109)	(0.0088)	(0.0022)	(0.0069)	(0.0079)	(0.3174)	(0.0354)
Organic milk	0.1566***	0.0041*	-0.0003	0.0362**	0.0052***	0.0339***	0.1266***	0.2429*	-0.6052***
	(0.0507)	(0.0030)	(0.0104)	(0.0153)	(0.0018)	(0.0105)	(0.0121)	(0.1882)	(0.1440)

Notes: Elasticities are calculated at the sample means. Values in the parentheses are the standard errors. Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level, respectively. Researcher(s)' own analyses calculated based on data from Circana procured in a contract with the International Dairy Foods Association.

Summary, Conclusions and Recommendations for Future Research

We adopt an LA-EASI model to analyze the demand structure for milk, taking into consideration flexible Engel curves, total expenditure and price endogeneity, and correcting for serial correlation. The weekly time-series data procured from Circana cover the time period going from the week ending on January 8, 2017 to the week ending on August 13, 2023, for a total of 345 observations, and are related to price and quantity associated with nine non-dairy and dairy product types. Based on the empirical results, the sextic/6th degree LA-EASI model was sufficient to capture the curvature of the Engel curves, which lends support to the statement that linear or quadratic degrees in real expenditures, which are widely utilized in empirical analysis, may not be the best specifications.

According to the uncompensated own-price elasticity estimates, the demands for almond, cashew, and oat milk alternatives as well as for lactose-free milk, and traditional white milk are elastic, while the demands for coconut, rice, and soy plant-based milk alternatives and organic milk are inelastic. The direct implication of this finding is that the manufacturers of almond, cashew, oat, lactose-free milk, and traditional white milk should consider a pricing strategy that envisions lowering prices to maximize their sales revenue in the short-run. At the same time, the manufacturers of coconut, rice, soy, and organic milk need to focus on a pricing strategy that would entail price increases to raise their short-run sales revenue.

Almond and oat are complements, while cashew and coconut are substitutes. No other substitutability and/or complementarity among PBMAs is evident. Lactose-free milk, traditional white milk, and organic milk are substitutes. The respective cow's milk categories and each of the PBMA categories are substitutes. From a competitive intelligence standpoint, the chief competitor to almond, cashew, oat, rice, and soy plant-based milk alternatives is traditional white milk. The principal competitor to lactose-free milk and organic milk also is traditional white milk. The chief competitor to traditional white milk and to coconut milk is almond milk.

Conditional on our set of disaggregated cow's milk and PBMA categories along with the use of the LA-EASI demand systems model as well as more current data, we provide evidence of notable differences in estimated own-price and cross-price elasticities as reported by the extant literature. Per the income elasticity estimates, all product types are necessities, which implies that producers and retailers can expect consistent demand and adjust their supply chain operations accordingly.

Moving forward, future work would benefit from adding bottled water, refrigerated and shelf-stable juices and drinks, and sports drinks to the mix of products to be considered along with health-enhanced milk products. This addition would provide a richer perspective on the demands for cow's milk products and plant-based milk products. Moreover, future endeavors could focus on employing microlevel (household) data associated with different product types, allowing attention to socio-demographic factors along with price and income elasticities. Also, future work should try and acquire data on input prices used in the production of milk as well as PBMA to expand the set of instruments for endogenous prices. Finally, future research should intend to incorporate penetration-adjusted quantities (for example, per capita consumption among consumers of specific milk types only) should such data be available. Notwithstanding these recommendations, this study makes a singular contribution to the extant literature on the demands for a disaggregated set of cow's milk products and plant-based milk alternatives.

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