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Demand Interrelationships of Peanuts and Tree Nuts in the United States

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By augmenting the Quadratic Almost Ideal Demand System model, a demand system analysis was conducted for peanuts and tree nuts in the United States. Monthly observations from 2004 through 2015 derived from the Nielsen Homescan Panel were used. The estimated uncompensated own-price elasticities for peanuts and the granular array of tree nuts considered ranged from -0.31 (pistachios) to -2.08 (almonds). Estimated income elasticities varied from 0.50 (walnuts) to 0.85 (pistachios), indicative of necessities. Substitutability and complementarity among the set of nut products were evident. The study contributes to the literature by providing a more up-to-date and thorough analysis of the demand for peanuts and tree nuts presently lacking in the extant literature.

Key words: Demand Interrelationships, Disaggregate Nut Products, Elasticities, Semi-LA/QUAIDS, Nielsen Homescan Data

About 40% of U.S. adults consume nuts on a regular basis (Nielsen, Kit, and Ogden, 2014). Nuts are energy-dense, protein-rich foods that are high in unsaturated fatty acids, dietary fiber, vitamins, and minerals. As such, the growth in the domestic demand for peanuts and tree nuts in the United States has been buoyed, in part, by their promotion as nutritious and healthy snacks by marketing boards and trade associations.

Annual per capita consumption of peanuts and tree nuts in the United States has been on the rise (Figure 1). In 2019, the per capita consumption of tree nuts was 5.2 pounds, up from 1.8 pounds in 1970, while the per capita consumption of peanuts was 7.5 pounds, up from 5.7 pounds in 1970. Tree nuts include almonds, Brazil nuts, cashews, chestnuts, hazelnuts (filberts), macadamias, pecans, pistachios, and walnuts. However, despite the nutritional value of nuts and attention by marketing boards and trade associations for nut products, little is known about the consumer demand associated with the consumption of peanuts and tree nuts.

The per capita consumption of specific tree nuts over the period 1970 to 2019 is exhibited in Figure 2. Across almost five decades, on average, the per capita consumption of tree nuts was as follows: (1) almonds - 0.93 pounds; (2) hazelnuts (filberts) - 0.06 pounds; (3) macadamias - 0.09 pounds; (4) pecans - 0.46 pounds; (5) pistachios - 0.15 pounds; (6) walnuts - 0.46 pounds; and (7) other tree nuts (defined as Brazil nuts, cashews, chestnuts, and pine nuts) - 0.67 pounds. The

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average per capita consumption from 1970 to 2019 was 6.51 pounds. The dominant tree nuts, in terms of per capita consumption, are almonds, pecans, walnuts, and other tree nuts. In the 2018-19 season, the total crop value of nuts was as follows: almonds $6.1 billion, hazelnuts $84.5 million, pecans $471.0 million, walnuts $1.29 billion, macadamias $48.9 million, pistachios $1.94 billion, total tree nuts $9.92 billion. These figures are indicative of the magnitude of the contribution of nut products to the U.S. agricultural economy. As well, the United States is the second largest producer of tree nuts worldwide (Asci and Devadoss, 2021).

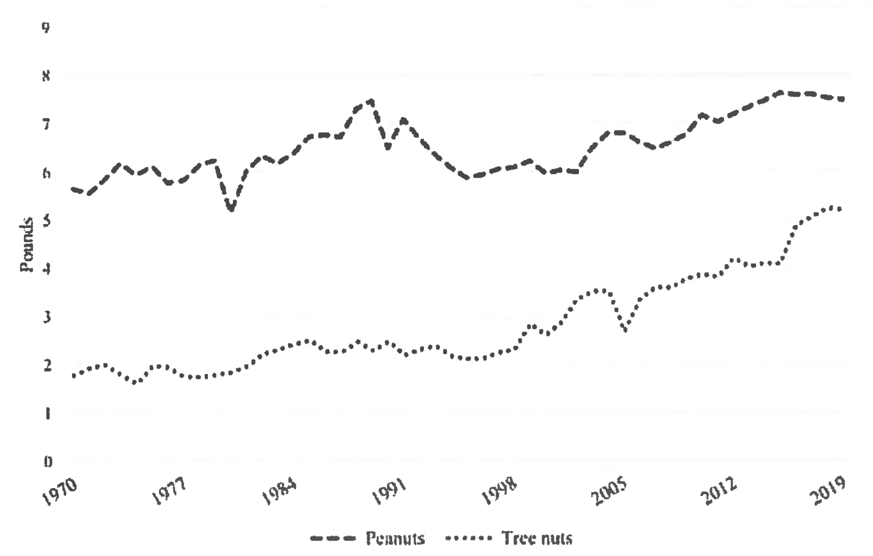

Figure 1. Annual U.S. Per Capita Consumption of Peanuts and Tree Nuts: 1970-2019.
Source: U.S. Department of Agriculture, Economic Research Service per capita availability data for peanuts and various issues of the Fruit and Nuts Yearbook for tree nuts.

To foster the marketing and promotion of almonds, walnuts, pistachios, and pecans, various Federal Marketing Orders (FMOs) were put into place under the auspices of the Agricultural Marketing Service of the U.S. Department of Agriculture (USDA). In 1948, FMO 984 established the California Walnut Board. In 1950, FMO 981 established the Almond Board of California. In 2004, FMO 983 established the Administrative Committee for Pistachios. Most recently, in 2016, FMO 986 established the American Pecan Council. As such, the growth in the domestic demand for peanuts and tree nuts has been buoyed, in part, by their promotion as nutritious and healthy snacks by marketing boards and trade associations.

Various studies have confirmed the association between the consumption of peanuts and tree nuts and health benefits (Ros, 2010; Van den Brandt and Schouten, 2015; de Souza, 2017). King et al. (2008) as well as Mattes, Kris-Etherton, and Foster (2008) revealed that the frequency of nut consumption and body mass index (BMI) are inversely related. Fraser et al. (1992) and Kris-Etherton et al. (2008) confirmed the benefits of tree nuts and peanuts in preventing coronary heart disease. Moreover, Jiang et al. (2002) found that nut and peanut butter consumption were inversely associated with the risk of type-2 diabetes in women. Further, tree nuts and peanuts have been recommended to be part of the daily intake of children and adults, replacing other snack foods (Rehm and Drewnowski, 2017). Additionally, Settaluri et al. (2012) highlighted the usefulness of considering peanuts as an essential component in the human diet. In the latest *Dietary Guidelines for Americans 2020-2025*, nuts are included in the spectrum of nutrient-dense foods and proteins (USDA and U.S. Department of Health and Human Services, 2020), further highlighting their importance in improving the health and nutrition status of consumers.

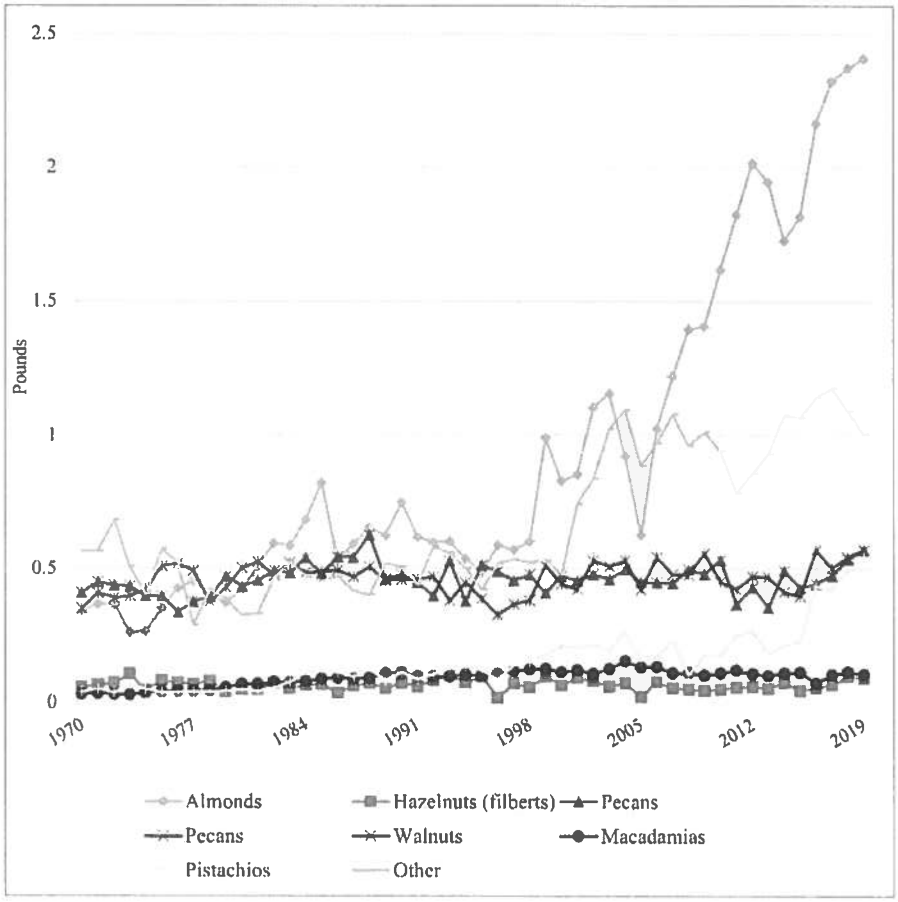

Figure 2. Annual U.S. Per Capita Consumption of Specific Tree Nuts: 1970-2019.
Source: U.S. Department of Agriculture, Economic Research Service per capita availability data for tree nuts and various issues of the Fruit and Nuts Yearbook for tree nuts.

Peanuts and tree nuts not only make notable contributions to the U.S. agricultural economy, but also health benefits are linked to the consumption of these commodities. Yet, relatively little is known about the economic factors associated with the consumption of peanuts and tree nuts. Exploring a detailed demand analysis for these products is worthwhile to commodity organizations such as the American Pecan Council, the Almond Board of California, the California Walnut Board, and the National Peanut Board, as well as other stakeholders in this industry.

In this light, the objectives of this research are to: (1) investigate demand interrelationships among peanuts and tree nuts in the United States; and (2) calculate own-price, cross-price, expenditure, and income elasticities for peanuts and tree nuts in the United States. The nut categories in this analysis correspond to peanuts, pecans, almonds, cashews, walnuts, macadamias, pistachios, mixed nuts, and other nuts. To address these objectives, monthly household purchase and expenditure data for the aforementioned nut categories are derived from the Nielsen Homescan Panel for the calendar years 2004 through 2015. The demand relationships are estimated using a variation of the Quadratic Almost Demand System. The estimated uncompensated own-price elasticities for peanuts and the granular array of tree nuts considered ranged from -0.31 to -2.08. Income elasticities of various nut products varied from 0.50 to 0.85. Substitutability and complementarity among the set of nut products also were evident. As such, we provide a more up-to-date and thorough analysis of the demand for peanuts and tree nuts presently lacking in the extant literature.

Literature Review

Lee (1950) estimated season's average returns to almond growers for the period 1924-1925 through 1948-1949 by using linear regression, including the domestic volume of almonds, volume imported, and prices of competing products as explanatory factors. The estimated own-price elasticities of demand for almonds varied from -0.46 to -5.03. Wells, Miller, and Thompson (1986) estimated farm-level demand for pecans using annual data from 1970-1982 based on a price-dependent demand function. The own-price flexibility of pecans at the farm level was estimated to be -0.97.

Lerner (1959) made the first attempt to investigate demand interrelationships of various tree nut products, examining improved pecans, seedling pecans, general pecans, walnuts, filberts, and almonds using annual time-series data from 1922-1955. Using a seemingly unrelated regression method, the estimated own-price elasticities were -2.73 for seedling pecans, -3.44 for improved pecans, -1.19 for general pecans, -1.80 for walnuts, -23.04 for filberts, and -0.86 for almonds. Pecans and walnuts were found to be gross complements. Pecans and filberts, pecans and almonds, and walnuts and almonds were found to be gross substitutes.

Dhaliwal (1972) examined demand interrelationships among eight tree nuts, including almonds, filberts, pecans, walnuts, pistachios, Brazil nuts, and cashews using annual time-series data from 1922-1955. The own-price elasticities were estimated to be -0.91 for pecans, -0.29 for walnuts, -1.93 for filberts, and -0.55 for almonds. Pecans and walnuts, pecans and Brazil nuts, and Brazil nuts and cashews were found to be gross substitutes; almonds and filberts as well as pecans and pistachios were found to be gross complements.

Russo, Green, and Howitt (2008) estimated the price and income elasticities of almonds and walnuts by utilizing a seemingly unrelated regression. Own-price elasticities for almonds were estimated to range from -0.35 to -0.48 and own-price elasticities for walnuts were estimated to range from -0.25 to -0.28. No substitution between almonds and walnuts was evident.

Using causality structures identified through machine learning methods, Kim and Dharmasena (2018) examined prices received by growers of pecans from 2005-2016 to investigate market integration patterns in Texas, Oklahoma, Georgia, and Louisiana. They found that current pecan prices received by growers in Texas were directly caused by pecan prices received in Oklahoma, Georgia, and Louisiana. Past period pecan prices in Georgia were found to influence current prices in other states. Similarly, Hawkins and Dharmasena (2019) examined prices received by peanut growers in Alabama, Florida, Georgia, North Carolina, Texas, and Virginia from 1982 through 2018 to discover market integration patterns. Results showed that Georgia and Texas are price leaders with their past and current prices influencing current prices in most of the other states.

Asci and Devadoss (2021) examined the trends of U.S. tree nut consumption and estimated price and expenditure elasticities for almonds, pistachios, walnuts, pecans, and hazelnuts. A general differential demand model conforming to regularity conditions was used in this analysis, based on annual observations from 1996 to 2018. The own-price elasticities ranged from -0.08 (pecans) to -1.29 (hazelnuts). Expenditure elasticities ranged from 0.53 (pecans) to 2.71 (hazelnuts). No consideration, however, was given to macadamias, cashews, mixed nuts, or peanuts. To the best of our knowledge, no other studies have examined demand interrelationships of tree nuts and peanuts subject to the granular level of detail provided in this research. Hence, our research adds to the literature by providing a more detailed analysis of demand interrelationships for tree nuts and peanuts in the United States.

Methodology

The Demand System Model

A semi-Linearized Quadratic Almost Ideal Demand System (semi-LA/QUAIDS) is used to analyze demand interrelationships for tree nuts and peanuts. Monthly observations over the period January 2004 through December 2015 derived from the Nielsen Homescan Panel were used in this analysis. By aggregating[1] the 144 monthly observations over all households in the Nielsen Homescan Panel, we avoid the data censoring issue inherent with the use of micro-level demand system models. The Quadratic Almost Ideal Demand System (QUAIDS) model as well as the Barten Synthetic model are appropriate specifications (Dharmasena and Capps, 2009; Dharmasena and Capps, 2012; and Lakkakula, Schmitz, and Ripplinger, 2016). To allow for nonlinear Engel curves, we chose the QUAIDS model as the demand system for this analysis, which retains all of the desirable properties of the AIDS model. To mitigate difficulties in estimation, as well as to deal with nonstationary variables (Matsuda 2006), a linearized version of this demand system was employed.

The model builds on previous work by Deaton and Muellbauer (1980) and Bank, Blundell, and Lewbel (1997). We suppose an indirect utility function $V(\boldsymbol{p}, m)$ given by equation (1)

$$(1)\quad \ln V(\boldsymbol{p}, m) = \left\{\left[\frac{\ln m - \ln a(\boldsymbol{p})}{b(\boldsymbol{p})}\right]^{-1} + \lambda(\boldsymbol{p})\right\}^{-1}.$$

[1] With this aggregation, we sacrifice the consideration of heterogeneity across households. In this context, we place emphasis on a *market-level analysis* as opposed to a *household-level analysis*.

$\ln a(\boldsymbol{p})$, $b(\boldsymbol{p})$, and $\lambda(\boldsymbol{p})$ are defined in equations (2), (3), and (4), respectively.

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

and

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

and

$$(4)\quad \lambda(\boldsymbol{p}) = \textstyle\sum_{i=1}^{n} \lambda_i \ln p_i.$$

where p_i refers to the price for the ith product, p_j refers to the price of the jth product, m corresponds to the total expenditure on the set of nut products in the demand system, n is the number of nut categories, $\boldsymbol{p}$ is the vector of prices of nut products, $\ln a(\boldsymbol{p})$ is the translog price aggregator, and $b(\boldsymbol{p})$ is the Cobb-Douglas price aggregator. α, β, γ, and λ are estimated parameters.

Then the budget share w_i for the ith product is given by the equation

$$(5)\quad w_i = \alpha_i + \textstyle\sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln[\frac{m}{a(p)}] + \frac{\lambda_i}{b(p)}\left\{\ln\left[\frac{m}{a(p)}\right]\right\}^2.$$

Equation (5) is tantamount to the QUAIDS of Bank, Blundell, and Lewbel (1997). In the empirical specification, we included quarterly dummies D_s in equation (6) to account for seasonality; d_{is} are the estimated parameters associated with the quarterly dummy variables for each nut product. For example, the consumption of pecans is higher during the Thanksgiving and Christmas holidays relative to other times of the year.

$$(6)\quad w_i = \alpha_i + \sum_{s=1}^{3} d_{is} D_s + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln[\frac{m}{a(\boldsymbol{p})}] + \frac{\lambda_i}{b(\boldsymbol{p})}\left\{\ln\left[\frac{m}{a(\boldsymbol{p})}\right]\right\}^2$$

Finally, adding up, homogeneity, and Slutsky symmetry restrictions are applied to conform to the consumer demand theory, as presented in equations (7)-(9).

$$(7)\quad \text{Adding} - \text{up:}\ \sum_{i=1}^{n} \alpha_i = 1,\quad \sum_{i=1}^{n} \beta_i = 0,\quad \sum_{i=1}^{n} \gamma_{ij} = 0,\quad \sum_{i=1}^{n} \lambda_i = 0;$$

$$(8)\quad \text{Homogeneity:}\ \sum_{j=1}^{n} \gamma_{ij} = 0;$$

$$(9)\quad \text{Slutsky symmetry:}\ \gamma_{ij} = \gamma_{ji}.$$

Price and Expenditure Elasticities

To calculate elasticities from this model, we differentiate equation (6) concerning the price and the expenditure terms. The expenditure elasticities (ε_i) are given as follows:

$$(10)\quad \varepsilon_i = 1 + \left(\frac{1}{w_i}\right)\left(\beta_i + \frac{2\lambda_i}{b(\boldsymbol{p})}\left\{\ln\left[\frac{m}{a(\boldsymbol{p})}\right]\right\}\right)$$

The uncompensated price elasticities (e_{ij}^u) are given by

$$(11)\quad e_{ij}^u = \left(\frac{1}{w_i}\right)\left(\begin{array}{c}\gamma_{ij} - \left(\beta_i + \frac{2\lambda_i}{b(\boldsymbol{p})}\left\{\ln\left[\frac{m}{a(\boldsymbol{p})}\right]\right\}\right)\left(\alpha_j + \sum_k \gamma_{jk} lnP_k\right) \\ -\frac{\lambda_i\beta_j}{b(\boldsymbol{p})}\left\{\ln\left[\frac{m}{a(\boldsymbol{p})}\right]\right\}^2\end{array}\right) - \delta_{ij}$$

where δ_{ij} is the Kronecker delta ($\delta_{ij} = 1$ if $i = j$ and $\delta_{ij} = 0$ if $i \neq j$). The compensated price elasticities e_{ij}^c, $e_{ij}^c = e_{ij}^u + \varepsilon_i w_j$ are derived using Slutsky's equation. Note that the respective elasticity calculations depend not only on the estimated parameters of the semi-LA/QUAIDS model, but also on prices, budget shares, and total expenditures on the various nut products.

Data

The data used are monthly observations over the period 2004 through 2015 derived from the Nielsen Company (US), LLC, and marketing databases provided by the Kilts Center for Marketing Data Center at The University of Chicago, Booth School of Business.[2] These data were the most recently available data to us at the time of this analysis. Despite this time frame without access to more recent years, our analysis provides a detailed update of the demand interrelationships among peanuts and tree nuts (at a disaggregated level) and, as such, adds to the extant literature. Importantly, too, our analysis serves as a baseline for future studies.

We categorized peanuts and tree nuts based on product module codes and product descriptions provided by Nielsen. Nielsen provided four general categorizations for nut products based on packaging type, including cans, jars, bags, and unshelled under the department of dry grocery. Further, Universal Product Code (UPC) description were used to define detailed products. The nine categories are: (1) peanuts,[3] (2) pecans, (3) almonds, (4) cashews, (5) walnuts, (6) macadamias, (7) pistachios, (8) mixed nuts, and (9) other nuts. Other nuts consist of Brazil nuts, nut toppings, pumpkin seeds, filberts, and sunflower seeds.

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[2] Disclaimer: The analyses provided by the researchers are 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 researchers 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.

[3] Peanut butter was not considered as part of the peanut category in this analysis.

In the Nielsen Homescan Panel, purchases of nuts are reported for each household over time, including the amount paid in dollars, the coupon value in dollars, and the amount purchased in ounces. Initially, we generated monthly purchases and expenditures of peanuts and tree nuts made by each household over the period from 2004 through 2015. Next, we aggregated the purchases and expenditures of peanuts and tree nuts over the respective households to form monthly figures. Then, we divided these figures by the corresponding number of households that purchased the corresponding nut category to arrive at monthly purchases and expenditures of peanuts and tree nuts on a per household basis. Because not all households purchased nuts in any given time, we further adjusted per household purchases and expenditures of peanuts and tree nuts taking into account the annual market penetration (see Appendix) for each respective nut category. The expenditure and quantity data subsequently are expressed in terms of dollars and ounces purchased per household per month.

Further, we calculated the monthly unit prices for each nut category by dividing monthly expenditures by monthly quantities purchased. Subsequently, we summed all expenditures of peanuts and tree nuts to derive total expenditure per month on a household basis. By dividing the expenditure of each nut type by total expenditure, we obtained the respective budget shares for peanuts and tree nuts per month. Bottom line, we generated monthly[4] purchases (ounces), unit values (prices) ($/ounce), and expenditures (dollars) over the period between 2004 and 2015 on a per household basis, a total of 144 observations for the respective nut products across the United States.

Descriptive Statistics

Descriptive statistics for prices ($/ounce), budget shares, quantities (ounces/month) corresponding to each of the nut categories, total expenditure ($/month), and income ($) are presented in Table 1. Macadamias were the most expensive nut product at $.71/ounce, followed by pecans, almonds, walnuts, pistachios, cashews, and mixed nuts. Peanuts were the least expensive product purchased at $.13/ounce.

Monthly purchases were highest for peanuts at 17.28 ounces per household on average, followed by monthly purchases of mixed nuts, cashews, and almonds at 7.98, 7.06, and 6.51 ounces purchased on average, respectively. Monthly purchases of walnuts, pistachios, other nuts, pecans, and macadamias per household were 5.23, 4.44, 3.82, 3.45, and 0.29 ounces on average, respectively. Over the 144 months, the averages of the budget shares were as follows: peanuts 0.15; pecans 0.11; almonds 0.15; cashews 0.15; walnuts 0.12; macadamias 0.01; pistachios 0.10; mixed nuts 0.16; and other nuts 0.06. Budget shares were highest for mixed nuts, peanuts, almonds, and cashews, followed by walnuts, pecans, and pistachios. Per household total expenditure for peanuts and tree nuts purchased at home was, on average, $15.32 per month over the period 2004 through 2015. Monthly income per capita over the period 2004 through 2015 was $36,543 on average.

[4] This process could be duplicated for any household socio-demographic factor including, but not limited to, various regions of the United States, as well as different races and ethnicity. Nevertheless, we chose to conduct a market-level analysis across all households in the United States.

Table 1. Descriptive Statistics of Prices, Budget Shares, Quantities, and Total Expenditure in the Demand System Analysis.

Item	Category	Mean	Standard Deviation	Minimum	Maximum
Prices ($/ounce)	Peanuts	0.13	0.02	0.11	0.17
	Pecans	0.48	0.07	0.32	0.62
	Almonds	0.35	0.05	0.25	0.50
	Cashews	0.33	0.07	0.20	0.43
	Walnuts	0.35	0.08	0.22	0.50
	Macadamias	0.71	0.14	0.51	0.99
	Pistachios	0.35	0.11	0.19	0.58
	Mixed Nuts	0.32	0.06	0.22	0.43
	Other Nuts	0.23	0.04	0.17	0.31
Budget Shares[b]	Peanuts	0.15	0.01	0.13	0.18
	Pecans	0.11	0.01	0.10	0.13
	Almonds	0.15	0.01	0.11	0.17
	Cashews	0.15	0.01	0.12	0.17
	Walnuts	0.12	0.01	0.10	0.14
	Macadamias	0.01	0.00[a]	0.01	0.02
	Pistachios	0.10	0.02	0.06	0.14
	Mixed Nuts	0.16	0.01	0.14	0.19
	Other Nuts	0.06	0.00[a]	0.05	0.07
Quantities Purchased (ounces/month)	Peanuts	17.28	1.13	13.98	20.27
	Pecans	3.45	0.37	2.78	4.56
	Almonds	6.51	1.25	3.79	9.19
	Cashews	7.06	1.41	4.90	10.35
	Walnuts	5.23	0.61	3.96	6.63
	Macadamias	0.29	0.09	0.11	0.46
	Pistachios	4.44	0.85	2.70	6.36
	Mixed Nuts	7.98	0.87	5.56	10.18
	Other Nuts	3.82	0.34	2.59	4.94
Expenditures ($/month)	Total Expenditure	15.32	1.88	12.09	18.55
Income ($/month)	Per Capita Income (DPI)[c]	36,543	3,462	29,958	42,847
PPI	Producer Price Index All Commodities[d]	182.59	19.28	141.40	208.30

[a] Budget share is less than 1%. [b] The budget shares added up to 1.01 due to rounding. [c] Disposable Personal Income, Federal Reserve Data Base, St. Louis, MO. [d] Producer Price Index for All Commodities [PPIACO], Federal Reserve Bank of St. Louis, MO. Source: Nielsen Homescan Panel 2004-2015, and calculations by the authors.

Estimation

Several issues need to be addressed in the estimation of our demand system model. First, given the nature of the data in the analysis, the presence of serial correlation needs to be examined through the autocorrelation and partial autocorrelation functions of the disturbance terms. Then we may express the system of demand functions as

$$(12)\quad w_{it} = \sum_{k} \rho_k\, w_{it-k} + f(x_{it}, \beta) - \sum_{k} \rho_k f(x_{it-k}, \beta) + \sum_{s=1}^{3} d_{is}\, D_s + \epsilon_{it}$$

where k is the number of lag terms and $f(x_{it}, \beta)$ is the function form from equation (6) (Berndt and Savin, 1975; Dharmasena and Capps, 2012; Hovhannisyan and Gould, 2014). The optimal lag of ρ_k is based on the autocorrelation and partial autocorrelation function of the error terms. Examination of these functions revealed an AR(1) process of the disturbance terms. Owing to adding-up, the estimation of a single ρ across the system was necessary to account for serial correlation.

The second issue centers attention on the endogeneity of prices and total expenditure in the QUAIDS model. 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, but this analysis rests on the use of data aggregated over households.

To mitigate this problem following Dhar, Chavas, and Gould (2003) as well as Lakkakula, Schmitz, and Ripplinger (2016), the endogeneity issue is addressed through the specification of reduced-form equations of prices and total expenditure, p_t and m_t (see equations (13) and (14)); the natural log of price p_t of any nut product 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 nut products. The use of the PPI in this analysis is reflective of supply-side variation in prices and, thus, is likely to be exogenous. To support this contention, PPIs were used as instruments in Lakkakula, Schmitz, and Ripplinger (2016). Also, the natural log of total expenditure m_t is regressed on the natural log of the income, $\ln \text{Income}_t$ as well as lags of total expenditure. This instrumental-variable method is similar to the works of Attfield (1985), Capps et al. (1994), Dharmasena and Capps (2012), and Lakkakula, Schmitz, and Ripplinger (2016). The reduced-forms associated with the use of this instrument variable process are:

$$(13)\quad lnp_t = \delta_t + \varphi_t lnPPI_t + \sum_{k=1}^{K} \eta_{kt} PPI_{t-k} + \sum_{k=1}^{K} \mu_{kt} lnp_{t-k} + \varepsilon_t$$

where, δ_t, φ_t, η_{kt}, and μ_{kt} are estimated parameters, k is the number of lags in each term, and

$$(14)\quad lnm_t = \phi_t + \zeta_t lnDPI_t + \sum_{k=1}^{K} \vartheta_{kt} m_{t-k} + e_t$$

where, ϕ_t, ζ_t, and ϑ_{kt} are estimated parameters and k is the number of lags in each term.

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 controlling for endogeneity (Dhar, Chavas, and Gould, 2003). The test statistic H is computed as follows,

$$(15)\quad H = (\boldsymbol{\beta} - \boldsymbol{\beta}_{IV})'(\text{var}(\boldsymbol{\beta}) - \text{var}(\boldsymbol{\beta}_{IV}))^{-1}(\boldsymbol{\beta} - \boldsymbol{\beta}_{IV})$$

where $\boldsymbol{\beta}$ is the vector of estimated coefficients without controlling for price and expenditure endogeneity, $\boldsymbol{\beta}_{IV}$ is the vector of estimated coefficients after controlling for endogeneity, and the term $\text{var}(\boldsymbol{\beta}) - \text{var}(\boldsymbol{\beta}_{IV})$ 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.

Moreover, a key concept in empirical demand analysis work, known as weak separability, is a necessary and sufficient condition for two-stage budgeting, according to (Deaton and Muellbauer 1980). Following the method introduced by Moschini, Moro, and Green (1994) and implemented by Lakkakula, Schmitz, and Ripplinger (2016), we test for weak separability. As exhibited in Table 2, we postulated two separable groups—one group for peanuts only and the other group containing the array of the respective tree nuts. Not only does the partition of peanuts and tree nuts make sense heuristically, but the reliance on separability cuts down on the number of parameters to be estimated, lowers the standard errors of the associated parameters, and helps to mitigate any degrading collinearity issues among the set of explanatory variables. To determine the number of non-redundant restrictions applied in our demand system, as suggested by Nayga and Capps (1994), seven non-redundant restrictions are evident as detailed in Table 2. The restrictions take the form as

$$(16)\quad \frac{\sigma_{ik}}{\sigma_{jk}} = \frac{\varepsilon_i}{\varepsilon_j}$$

where σ_{ik} and σ_{jk} are the elasticity of substitution between tree nuts i and peanuts k and tree nuts j and peanuts k; and ε_i and ε_j the expenditure elasticities of tree nuts i and tree nuts j. In our case, weak separability implies that the marginal rate of substitution between any two tree nuts is independent of the quantity of peanuts. Then we arrive at the parametric restrictions[5] tested in the system at the sample means as

$$(17)\quad \frac{\gamma_{ik} + \alpha_i\alpha_k}{\gamma_{jk} + \alpha_j\alpha_k} = \frac{\beta_i + \alpha_i}{\beta_j + \alpha_j}$$

The parametric restrictions, derived in Moschini, Moro, and Green (1994) as well as Lakkakula, Schmitz, and Ripplinger (2016), are tested using a Wald-test distributed as a chi-squared statistic.

Finally, according to Matsuda (2006), unless linearly approximated, nonlinear systems including the QUAIDS are not amenable in dealing with nonstationary variables. As exhibited in Table 3, prices and total expenditure are nonstationary based on Augmented Dickey-Fuller tests. 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

$$(18)\quad \ln a(\boldsymbol{p}) = \textstyle\sum_i w_{it-1} \ln p_{it}.$$

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

[5] We restricted α_0 to be zero.

shares by one period in equation (18). To preserve nonlinear Engel curves (available upon request), the Cobb-Douglas price aggregator $b(\boldsymbol{p})$ in the QUAIDS model was kept and used in the estimation. Bottom line, the semi-LA/QUAIDS is defined by incorporating equations (3), (7), (8), (9), (12), and (18).

Table 2. Structure of Separable Demand Models and Summary of Non-Redundant Restrictions.

Commodity	**Separable Grouping**
Peanuts	A
Pecans	B
Almonds	B
Cashews	B
Walnuts	B
Macadamias	B
Pistachios	B
Mixed Nuts	B
Other Nuts	B
Non-redundant Restrictions	
Group $B_{i,j}$	**Group A_k**
Pecans, Almonds	Peanuts
Almonds, Cashews	Peanuts
Cashews, Walnuts	Peanuts
Walnuts, Macadamias	Peanuts
Macadamias, Pistachios	Peanuts
Pistachios, Other Nuts	Peanuts
Other Nuts, Mixed Nuts	Peanuts

Note: Test for weak separability, following Moschini, Moro, and Green (1994) and Sellen and Goddard a(1997), and Lakkakula, Schmitz, and Ripplinger (2016). The number of non-redundant restrictions is calculated following Nayga and Capps (1994). The parametric restrictions tested in the demand system is as follows below. Source: Nielsen Homescan Panel 2004-2015, and calculations by the authors. $\frac{\gamma_{ik} + \alpha_i\alpha_k}{\gamma_{jk} + \alpha_j\alpha_k} = \frac{\beta_i + \alpha_i}{\beta_j + \alpha_j}$

Table 3. Augmented Dickey-Fuller (ADF) Tests for Stationarity of Price and Total Expenditure.

Commodity	Test Statistics	MacKinnon approximate p-value
Budget Shares		
Peanuts	-3.34	0.01
Pecans	-4.15	0.00
Almonds	-3.62	0.01
Cashews	-2.26	0.19
Walnuts	-2.96	0.04
Macadamias	-2.64	0.09
Pistachios	-1.69	0.44
Mixed Nuts	-2.78	0.06
Other Nuts	-5.89	0.00
Prices		
Peanuts	-1.14	0.70
Pecans	-2.21	0.20
Almonds	0.59	0.99
Cashews	-1.03	0.74
Walnuts	-1.41	0.58
Macadamias	-1.24	0.66
Pistachios	0.11	0.97
Mixed Nuts	-1.21	0.67
Other Nuts	-1.43	0.57
Total Expenditures	-2.24	0.19

Note: The null hypothesis associated with the Augmented Dickey-Fuller test is that all variables follow a unit-root process and are, subsequently, nonstationary.

Empirical Results

The estimation of the aforementioned instrumental variable process was done using SAS© software, Version 9.4. The detailed specifications, estimated coefficients, and *p*-values associated with the estimated coefficients are presented in Table 4. The majority of the coefficients estimated based on the instrument variables were significant at the 10% level. As exhibited in Tables 4, bold numbers indicate significance at the 10% level. The goodness-of-fit (R^2) ranged from 0.84 to 0.99 and Durbin-Watson statistics varied from 1.55 to 2.30.

Predicted values of p_t and m_t based on equation (13) and (14) were subsequently plugged back in the demand system model. We derive the income elasticity as follows:

$$(19)\quad IE_i = \frac{\%\Delta \text{ Total Expenditure}}{\%\Delta \text{ Income}} \times \frac{\%\Delta \text{ Quantity Demanded}_i}{\%\Delta \text{ Total Expenditure}} = 0.64 \times \varepsilon_i,$$

where IE_i is the income elasticity for nut i, ε_i is expenditure elasticity derived from equation (10), 0.64 is the estimated coefficient (c) from equation (12), and %Δ depicts the percentage change of each variable.

The price and expenditure figures were replaced with predicted values from reduced forms for each nut category accordingly. Further, the semi-LA/QUAIDS model also was estimated using SAS© software, Version 9.4, through the use of an iterative seemingly unrelated regression procedure (ITSUR).[6] To accommodate the singularity issue of the variance-covariance matrix of the system of equations generated through the adding-up condition of budget shares, we dropped one equation from the estimation process. Arbitrarily, the omitted equation was associated with mixed nuts.

We recovered all coefficients for mixed nuts using equation (7). Goodness-of-fit statistics R^2 and adjusted R^2 as well as Durbin-Watson statistics are provided in Table 5. The R^2 metrics for the semi-LA/QUAIDS model ranged from 0.51 to 0.92. The model was corrected for serial correlation using an AR(1) process in the disturbance terms as previously discussed; as exhibited in Table 5, r1 is the estimated parameter associated with this AR(1) process. The Durbin-Watson statistics corresponding to this demand system ranged from 1.64 to 2.61, thereby providing evidence of the absence of first-order autocorrelation in the error terms. Also, the mean absolute percent error (MAPE) for the respective equations varied from 1.63% to 8.87%, indicative of the ability of the model to mimic actual budget shares.

[6] The ITSUR procedure does not depend on any distribution of the error terms, whereas the full information maximum likelihood (FIML) requires an underlying multivariate distribution (typically the assumption of normality). However, the dependent variables are budget shares so the appropriate distribution in this analysis would be a Dirichlet distribution (multivariate distribution of the beta distribution) because the budget shares vary from 0 to 1. We estimated the demand system using FIML, but the results underperformed those produced by the ITSUR technique.

Table 4. Parameter Estimates and Associated p-Values for Reduced-Form Equations of Total Expenditure and Prices of Tree Nuts and Peanuts.

Expenditure-Income (Dependent Variable:		**$\ln(\text{Total Expenditure})_t$)**	**Price of Almonds (Dependent Variable:**		**$\ln(\text{Price Almonds})_t$)**
Variables	Estimate	p-value	Variables	Estimate	p-value
Constant	**-4.10**	0.08	Constant	**-2.58**	0.00
$\ln(\text{DPI})_t$	**0.64**	0.00	$\ln(\text{PPI})_{t-3}$	**0.26**	0.07
$\ln(\text{Total Expenditure})_{t-1}$	**0.51**	0.00	$\ln(\text{Price Almonds})_{t-1}$	**1.90**	0.00
$\ln(\text{Total Expenditure})_{t-2}$	**0.44**	0.00	$\ln(\text{Price Almonds})_{t-2}$	**-0.90**	0.00
Error Term_{t-12}	**-0.68**	0.00	Error Term_{t-1}	**0.80**	0.00
Goodness-of-fit	R^2	0.94	Goodness-of-fit	R^2	0.97
	Adjusted R^2	0.93		Adjusted R^2	0.97
	Durbin-Watson	2.04		Durbin-Watson	2.08
Price of Peanuts (Dependent Variable:		**$\ln(\text{Price Peanuts})_t$)**	**Price of Cashews (Dependent Variable:**		**$\ln(\text{Price Cashews})_t$)**
Variables	Estimate	p-value	Variables	Estimate	p-value
Constant	**-4.11**	0.00	Constant	**-2.32**	0.01
$\ln(\text{PPI})_{t-3}$	**0.40**	0.00	$\ln(\text{PPI})_{t-2}$	0.28	0.11
$\ln(\text{Price Peanuts})_{t-1}$	**0.95**	0.00	$\ln(\text{Price Cashews})_{t-2}$	**0.96**	0.00
Error Term_{t-12}	**-0.32**	0.00	Error Term_{t-1}	**-0.97**	0.00
Goodness-of-fit	R^2	0.96	Goodness-of-fit	R^2	0.99
	Adjusted R^2	0.96		Adjusted R^2	0.99
	Durbin-Watson	2.09		Durbin-Watson	2.18
Price of Walnuts (Dependent Variable:		**$\ln(\text{Price Walnuts})_t$)**	**Price of Pistachios (Dependent Variable:**		**$\ln(\text{Price Pistachios})_t$)**
Variables	Estimate	p-value	Variables	Estimate	p-value
Constant	**-3.71**	0.00	Constant	0.13	0.96
$\ln(\text{PPI})_t$	**0.55**	0.01	$\ln(\text{PPI})_{t-1}$	**-0.50**	0.01
$\ln(\text{Price Walnuts})_{t-1}$	**0.98**	0.00	$\ln(\text{PPI})_{t-2}$	**0.54**	0.01
Goodness-of-fit	R^2	0.98	$\ln(\text{Price Pistachios})_{t-1}$	**1.00**	0.00
	Adjusted R^2	0.98	Goodness-of-fit	R^2	0.99
	Durbin-Watson	1.65		Adjusted R^2	0.99
				Durbin-Watson	2.21
Price of Macadamias (Dependent Variable:		**$\ln(\text{Price Macadamias})_t$)**	**Price of Pecans (Dependent Variable:**		**$\ln(\text{Price Pecans})_t$)**
Variables	Estimate	p-value	Variables	Estimate	p-value
Constant	**-6.30**	0.00	Constant	**-5.88**	0.00
$\ln(\text{PPI})_t$	**1.14**	0.00	$\ln(\text{PPI})_t$	**0.99**	0.00
Error Term_{t-1}	**-1.07**	0.00	Error Term_{t-1}	**-1.08**	0.00
Error Term_{t-2}	**-0.52**	0.00	Error Term_{t-2}	**-0.91**	0.00
Goodness-of-fit	R^2	0.84	Error Term_{t-3}	**-0.51**	0.00
	Adjusted R^2	0.83	Goodness-of-fit	R^2	0.91
	Durbin-Watson	1.55		Adjusted R^2	0.91
				Durbin-Watson	1.67
Price of Mixed Nuts (Dependent Variable:		**$\ln(\text{Price Mixed Nuts})_t$)**	**Price of Other Nuts (Dependent Variable:**		**$\ln(\text{Price Other Nuts})_t$)**
Variables	Estimate	p-value	Variables	Estimate	p-value
Constant	**-2.82**	0.00	Constant	**-3.66**	0.00
$\ln(\text{PPI})_{t-1}$	**0.26**	0.00	$\ln(\text{PPI})_t$	**0.43**	0.06
$\ln(\text{Price Mixed Nuts})_{t-1}$	**1.00**	0.00	$\ln(\text{Price Other Nuts})_{t-1}$	**0.93**	0.00
Error Term_{t-1}	**0.44**	0.00	Error Term_{t-12}	**-0.32**	0.00
Error Term_{t-12}	**-0.67**	0.00	Goodness-of-fit	R^2	0.95
Goodness-of-fit	R^2	0.97		Adjusted R^2	0.94
	Adjusted R^2	0.97		Durbin-Watson	2.30
	Durbin-Watson	1.60			

Note: We used disposable personal income (DPI) as an instrument for the total expenditure and the producer price index (PPI) for all commodities as an instrument for prices of peanuts and tree nuts. Bold numbers indicate significance at the 10% level. Source: Nielsen Homescan Panel 2004-2015 and Federal Reserve Data Base, St. Louis, MO, and calculations by the authors.

Parameters, Endogeneity, Weak Separability, and Seasonality

All of the estimated parameters and associated p-values are shown in Table 5. Bold numbers indicate that estimated coefficients are considered to be significantly different from zero provided that the corresponding p-values are equal to or less than 0.10. Given the number of observations, the 10% level of significance was chosen for our analysis. Twenty-three out of the 45_estimated gamma parameters, γ_{ij}, were statistically different from zero, while six out of the nine estimated alpha parameters, and seven out of the nine estimated beta parameters, were statistically different from zero. The estimated autocorrelation coefficient (r1) was statistically different from zero. Seven out of nine lambda parameters were significant individually and jointly which indicates the presence of nonlinear Engel curves. The estimated DWH chi-squared test statistic is 1,954.91 (p-value < 0.01) (see Table 5). Hence, controlling for price and expenditure endogeneity is necessary to consistently estimate the parameters of the semi-LA/QUAIDS.

Seven non-redundant restrictions regarding weak separability were tested using the Wald test. As exhibited in Table 5, we fail to reject the null hypothesis of weak separability between peanuts and tree nuts.

Quarterly dummies were included in each equation to capture seasonality. As shown in Table 5, seasonality was evident for pecans, almonds, cashews, walnuts, and other nuts. No seasonal pattern was found for peanuts, macadamias, pistachios, and mixed nuts. Generally, consumption of pecans and other nuts was higher in the fourth quarter and consumption of almond and walnuts was lower in the fourth quarter.

Uncompensated and Compensated Price Elasticities

We calculated uncompensated, compensated own-price and cross-price elasticities, and expenditure elasticities for each data point (144 months from January 2004 through December 2015) for each nut category. The respective elasticities are dependent not only on the estimated parameters, but also on prices, total expenditure, and budget shares. We perform t-tests[7] on each of the respective elasticity estimates, and we report the standard errors and associated significance levels. We hypothesize that all own-price elasticities are negative as stipulated by economic theory, and we hypothesize that all expenditure elasticities are positive.

Uncompensated own-price and cross-price elasticities are exhibited in Table 6. These respective elasticities correspond to the means of the respective 144 monthly observations over the sample period from January 2004 to December 2015. All nine own-price elasticities were statistically significant, ranging from -0.31 to -2.08. In particular, the demands for peanuts, pecans, almonds, cashews, macadamias, mixed nuts, and other nuts were elastic, while the demands for walnuts and pistachios were inelastic.

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[7] One-tailed tests for expenditure elasticities, one-tailed tests for own-price elasticities, and two-tailed tests for cross-price elasticities were done.

Table 5. Nonlinear ITSUR Parameter Estimates and Associated p-Values, Joint Test of Seasonality, Endogeneity Test, and Model Goodness-of-Fit Statistics.

params	Estimate	p-value	params	Estimate	p-value	params	Estimate	p-value
Gammas			**Gammas**			**Gammas**		
gpeanutpeanut	-0.08	0.20	gpecanother	0.05	0.12	gwalnutwalnut	**0.03**	0.03
gpeanutpecan	**-0.10**	0.00	gpecanmix	**-0.12**	0.01	gwalnutmaca	0.00	0.79
gpeanutalmond	**0.12**	0.01	galmondalmond	**-0.16**	0.02	gwalnutpistachio	-0.01	0.32
gpeanutcashew	**0.11**	0.03	galmondcashew	**-0.11**	0.02	gwalnutother	0.00	0.90
gpeanutwalnut	0.00	1.00	galmondwalnut	-0.01	0.76	gwalnutmix	-0.01	0.80
gpeanutmaca	**0.04**	0.04	galmondmaca	**-0.04**	0.05	gmacamaca	-0.01	0.31
gpeanutpistachio	-0.03	0.47	galmondpistachio	0.00	0.98	gmacapistachio	0.00	0.79
gpeanutother	**0.06**	0.10	galmondother	**-0.07**	0.05	gmacaother	-0.02	0.15
gpeanutmix	**-0.12**	0.01	galmondmix	**0.15**	0.02	gmacamix	**0.04**	0.09
gpecanpecan	**-0.09**	0.08	gcashewcashew	**-0.16**	0.05	gpistachiopistachio	**0.07**	0.00
gpecanalmond	**0.12**	0.01	gcashewwalnut	0.00	0.94	gpistachioother	0.01	0.63
gpecancashew	**0.11**	0.02	gcashewmaca	**-0.04**	0.08	gpistachiomix	-0.02	0.69
gpecanwalnut	0.02	0.66	gcashewpistachio	0.00	0.99	gotherother	-0.03	0.27
gpecanmaca	**0.03**	0.06	gcashewother	**-0.06**	0.10	gothermix	0.06	0.14
gpecanpistachio	-0.02	0.61	gcashewmix	**0.15**	0.02	gmixmix	-0.01	0.84
Alphas			**Betas**			**Lambdas**		
apeanut	**0.55**	0.00	bpeanut	**-0.22**	0.00	lampeanut	**0.03**	0.01
apecan	**0.49**	0.00	bpecan	**-0.22**	0.00	lampecan	**0.03**	0.00
aalmond	**-0.30**	0.00	balmond	**0.28**	0.00	lamalmond	**-0.04**	0.00
acashew	**-0.27**	0.06	bcashew	**0.25**	0.00	lamcashew	**-0.04**	0.00
awalnut	0.13	0.30	bwalnut	0.01	0.88	lamwalnut	-0.01	0.63
amaca	**-0.12**	0.03	bmaca	**0.08**	0.02	lammaca	**-0.01**	0.04
apistachio	0.04	0.76	bpistachio	-0.01	0.88	lampistachio	0.01	0.61
aother	-0.10	0.35	bother	**0.11**	0.09	lamother	**-0.02**	0.09
amix	**0.58**	0.00	bmix	**-0.27**	0.00	lammix	**0.04**	0.00
AR (1)			**Lambdas Joint Test**	**Chi-Squared Statistic**				**p-value**
r1	**0.79**	0.00		**83.40**				0.00

Seasonal dummies

dummies	Estimate	p-value	dummies	Estimate	p-value	dummies	Estimate	p-value
dpeanut1	-0.0008	0.35	dcashew1	**-0.0027**	0.01	dpistachio1	0.0028	0.13
dpeanut2	-0.0010	0.24	dcashew2	-0.0013	0.19	dpistachio2	**0.0029**	0.10
dpeanut3	-0.0012	0.16	dcashew3	-0.0005	0.60	dpistachio3	0.0008	0.64
dpecan1	**-0.0073**	0.00	dwalnut1	**0.0025**	0.01	dother1	**-0.0040**	0.00
dpecan2	**-0.0047**	0.00	dwalnut2	0.0012	0.20	dother2	**-0.0032**	0.00
dpecan3	**-0.0042**	0.00	dwalnut3	0.0011	0.19	dother3	**-0.0014**	0.03
dalmond1	**0.0103**	0.00	dmaca1	**-0.0007**	0.10	dmix1	-0.0001	0.91
dalmond2	**0.0047**	0.00	dmaca2	-0.0002	0.64	dmix2	**0.0017**	0.10
dalmond3	**0.0061**	0.00	dmaca3	-0.0004	0.23	dmix3	-0.0003	0.73

Joint Test of Seasonal Dummies[a] / **Goodness-of-Fit**

Null Hypothesis	Chi-squared Statistic	p-value	Equation	R^2	Adjusted R^2	Durbin Watson	MAPE
dpeanut1=dpeanut2=dpeanut3=0	2.24	0.52	Peanuts	0.9000	0.8926	2.3223	1.63%
dpecan1=dpecan2=dpecan3=0	**60.13**	0.00	Pecans	0.7424	0.7231	2.4880	2.57%
dalmond1=dalmond2=dalmond3=0	**65.35**	0.00	Almonds	0.8381	0.8259	2.1689	2.58%
dcashew1=dcashew2=dcashew3=0	**7.51**	0.06	Cashews	0.9126	0.9060	1.8796	2.03%
dwalnut1=dwalnut2=dwalnut3=0	**6.60**	0.09	Walnuts	0.8388	0.8267	2.1712	2.02%
dmaca1=dmaca2=dmaca3=0	3.36	0.34	Macadamias	0.8385	0.8264	2.6078	8.87%
dpistachio1=dpistachio2=dpistachio3=0	3.89	0.27	Pistachios	0.9225	0.9167	1.6440	5.08%
dother1=dother2=dother3=0	**38.63**	0.00	Other Nuts	0.5119	0.4753	2.4447	3.30%
dmix1=dmix2=dmix3=0	5.91	0.12	Mixed Nuts[b]	0.8308	0.8182	2.2281	1.75%

Durbin-Wu-Hausman Test for Price and Expenditure Endogeneity

Endogeneity test	Degree of Freedom	Chi-Squared Statistic	p-value
H-statistic	94	**1,954.91**	0.00

Non-redundant Restrictions Wald Tests

Group B $_{ij}$	Group A $_{k}$	Chi-Squared Statistic	p-value	Parametric Restrictions
Pecans, Almonds	Peanuts	0.120	0.72	$\frac{\gamma_{ik} + \alpha_i \alpha_k}{\gamma_{jk} + \alpha_j \alpha_k} = \frac{\beta_i + \alpha_i}{\beta_j + \alpha_j}$
Almonds, Cashews	Peanuts	0.010	0.94	
Cashews, Walnuts	Peanuts	0.890	0.34	
Walnuts, Macadamias	Peanuts	1.860	0.17	For example, pecans and almonds with respect to peanuts.
Macadamias, Pistachios	Peanuts	0.010	0.94	
Pistachios, Other Nuts	Peanuts	0.000	0.99	$\frac{\text{gpeanutpecan} + \text{apeanut} * \text{apecan}}{\text{gpeanutalmond} + \text{apeanut} * \text{aalmond}} = \frac{\text{bpecan} + \text{apecan}}{\text{balmond} + \text{aalmond}}$
Other Nuts, Mixed Nuts	Peanuts	0.200	0.65	

[a] *The base quarter season is the last quarter, d(nut's name)1 is the dummy for the first season, and so on.* [b] *After we recovered the parameters for mixed nuts using adding-up restrictions (equation (7)), we calculated the predicted values of budget shares of mixed nuts, and then derived the goodness-of-fit, R^2, adjusted R^2, and Durbin Watson statistic for mixed nuts. Note: Bold numbers indicate significance at the 10% level. Source: Nielsen Homescan Panel 2004-2015, and calculations by the authors.*

Table 6. Uncompensated Own-Price and Cross-Price, Expenditure, and Income Elasticities.

Category	Peanuts	Pecans	Almonds	Cashews	Walnuts	Macadamias	Pistachios	Other Nuts	Mixed Nuts	Expenditure Elasticity	Income Elasticity
Peanuts	-1.5238	-0.6889	0.8441	0.7520	0.0035	0.2680	-0.1733	0.3805	-0.8246	0.9625	0.6160
	(0.0028)	(0.0037)	(0.0051)	(0.0046)	(0.0008)	(0.0015)	(0.0010)	(0.0023)	(0.0044)	(0.0069)	
Pecans	-0.9694	-1.8623	1.1449	1.0462	0.1435	0.3105	-0.1791	0.4711	-1.0957	0.9903	0.6338
	(0.0053)	(0.0047)	(0.0059)	(0.0055)	(0.0013)	(0.0016)	(0.0015)	(0.0024)	(0.0060)	(0.0099)	
Almonds	0.8692	0.8419	-2.0846	-0.7640	-0.0770	-0.2653	0.0190	-0.4590	1.0185	0.9016	0.5770
	(0.0079)	(0.0074)	(0.0089)	(0.0059)	(0.0012)	(0.0021)	(0.0010)	(0.0037)	(0.0091)	(0.0103)	
Cashews	0.7543	0.7548	-0.7813	-2.0790	-0.0223	-0.2621	0.0026	-0.3893	0.9936	1.0287	0.6584
	(0.0058)	(0.0058)	(0.0060)	(0.0083)	(0.0009)	(0.0020)	(0.0008)	(0.0030)	(0.0077)	(0.0080)	
Walnuts	0.0319	0.1530	-0.0780	0.0094	-0.7385	-0.0256	-0.0675	-0.0068	-0.0566	0.7786	0.4983
	(0.0005)	(0.0010)	(0.0006)	(0.0004)	(0.0015)	(0.0001)	(0.0007)	(0.0001)	(0.0003)	(0.0024)	
Macadamias	3.2466	2.6925	-3.2425	-3.1904	-0.3018	-1.8942	-0.3163	-1.5139	3.2976	1.2236	0.7831
	(0.0761)	(0.0633)	(0.0805)	(0.0794)	(0.0101)	(0.0217)	(0.0100)	(0.0375)	(0.0770)	(0.0382)	
Pistachios	-0.3355	-0.2428	-0.0327	-0.0414	-0.1509	-0.0432	-0.3139	0.0825	-0.2545	1.3326	0.8529
	(0.0074)	(0.0053)	(0.0006)	(0.0014)	(0.0031)	(0.0010)	(0.0150)	(0.0017)	(0.0057)	(0.0078)	
Other Nuts	0.9867	0.8753	-1.1818	-0.9875	-0.0371	-0.3178	0.1663	-1.5492	1.0698	0.9758	0.6245
	(0.0056)	(0.0048)	(0.0057)	(0.0048)	(0.0010)	(0.0016)	(0.0014)	(0.0027)	(0.0061)	(0.0093)	
Mixed Nuts	-0.7707	-0.7243	0.8919	0.8905	-0.0739	0.2483	-0.1200	0.3721	-1.7782	1.0644	0.6812
	(0.0035)	(0.0033)	(0.0042)	(0.0044)	(0.0010)	(0.0012)	(0.0011)	(0.0018)	(0.0036)	(0.0081)	

Note: The estimated elasticities correspond to the means of 144 monthly values for the period 2004 to 2015. Bold numbers indicate significance at the 1% level; the numbers below the estimated elasticities correspond to the standard errors over the time period 2004 to 2015. Income elasticities are calculated using equation (19) by multiplying estimates of expenditure elasticities by the coefficient 0.64. The significance of income elasticities is based on the statistical significance of the expenditure elasticities. Source: Nielsen Homescan Panel 2004-2015, and calculations by the authors.

Table 7. Compensated Own-Price and Cross-Price Elasticities.

Category	Peanuts	Pecans	Almonds	Cashews	Walnuts	Macadamias	Pistachios	Other Nuts	Mixed Nuts
Peanuts	-1.3797	-0.5864	0.9857	0.8942	0.1161	0.2808	-0.0786	0.4357	-0.6678
	(0.0038)	(0.0042)	(0.0056)	(0.0033)	(0.0007)	(0.0013)	(0.0014)	(0.0022)	(0.0052)
Pecans	-0.8210	-1.7568	1.2905	1.1925	0.2592	0.3879	-0.0817	0.5279	-0.9343
	(0.0055)	(0.0050)	(0.0066)	(0.0047)	(0.0012)	(0.0018)	(0.0016)	(0.0024)	(0.0060)
Almonds	1.0033	0.9380	-1.9514	-0.6313	0.0290	-0.2537	0.1082	-0.4071	1.1650
	(0.0078)	(0.0072)	(0.0101)	(0.0056)	(0.0013)	(0.0020)	(0.0020)	(0.0038)	(0.0088)
Cashews	0.9077	0.8645	-0.6296	-1.9273	0.0985	-0.2487	0.1041	-0.3301	1.1610
	(0.0051)	(0.0054)	(0.0052)	(0.0093)	(0.0007)	(0.0022)	(0.0021)	(0.0030)	(0.0070)
Walnuts	0.1481	0.2360	0.0368	0.1242	-0.6471	-0.0154	0.0094	0.0380	0.0701
	(0.0009)	(0.0011)	(0.0016)	(0.0011)	(0.0007)	(0.0002)	(0.0023)	(0.0003)	(0.0006)
Macadamias	3.4279	2.8230	-3.0620	-3.0103	-0.1571	-1.8789	-0.1946	-1.4433	3.4964
	(0.0784)	(0.0652)	(0.0768)	(0.0769)	(0.0063)	(0.0218)	(0.0057)	(0.0362)	(0.0799)
Pistachios	-0.1356	-0.1004	0.1628	0.1564	0.0050	-0.0254	-0.1848	0.1590	-0.0368
	(0.0053)	(0.0040)	(0.0010)	(0.0013)	(0.0027)	(0.0006)	(0.0130)	(0.0021)	(0.0036)
Other Nuts	1.1321	0.9794	-1.0379	-0.8437	0.0775	-0.3052	0.2626	-1.4931	1.2286
	(0.0052)	(0.0044)	(0.0061)	(0.0050)	(0.0008)	(0.0016)	(0.0022)	(0.0031)	(0.0057)
Mixed Nuts	-0.6114	-0.6110	1.0485	1.0477	0.0506	0.2624	-0.0151	0.4331	-1.6048
	(0.0042)	(0.0035)	(0.0049)	(0.0032)	(0.0006)	(0.0009)	(0.0017)	(0.0018)	(0.0042)

Note: The estimated elasticities correspond to the means of 144 monthly values for the period 2004 to 2015. Bold numbers indicate significance at the 1% level; the numbers below the estimated elasticities correspond to the standard errors over the time period 2004 to 2015. Source: Nielsen Homescan Panel 2004-2015, and calculations by the authors.

Table 8. Evidence of Substitutability and Complementarity among Nut Categories.

Commodity	Substitutes	Complements
Peanuts	Almonds, Cashews, Other Nuts, Macadamias, and Walnuts	Mixed Nuts, Pecans, and Pistachios
Pecans	Almonds, Cashews, Other Nuts, Macadamias, and Walnuts	Mixed Nuts, Peanuts, and Pistachios
Almonds	Mixed Nuts, Peanuts, Pecans, Pistachios, and Walnuts	Cashews, Other Nuts, and Macadamias
Cashews	Mixed Nuts, Peanuts, Pecans, Pistachios, and Walnuts	Almonds, Other Nuts, and Macadamias
Walnuts	Pecans, Peanuts, Cashews, Mixed Nuts, Other Nuts, Almonds, and Pistachios	Macadamias
Macadamias	Mixed Nuts, Peanuts, and Pecans	Almonds, Cashews, Other Nuts, Pistachios, and Walnuts
Pistachios	Almonds, Other Nuts, Cashews, and Walnuts	Peanuts, Pecans, Mixed Nuts, and Macadamias
Other Nuts	Mixed Nuts, Peanuts, Pecans, Pistachios, and Walnuts	Almonds, Cashews, and Macadamias
Mixed Nuts	Almonds, Cashews, Other Nuts, Macadamias, and Walnuts	Peanuts, Pecans, and Pistachios

Note: The substitutes and complements are ordered based on the magnitude of the compensated cross-price elasticities. Source: Evidence compiled from the respective compensated cross-price elasticities.

Table 9. Comparison of Models, Data, Nut Products, Own-Price Elasticities with Other Studies in the Literature.

Study	Model	Data	Nut Products	Own-Price Elasticity	
This article	Semi-LA/QUAIDS	Monthly time-series 2004-2015 from Nielsen HomeScan Panel	Peanuts	-1.524	
			Pecans	-1.862	
			Almonds	-2.085	
			Cashews	-2.079	
			Walnuts	-0.739	
			Macadamias	-1.894	
			Pistachios	-0.314	
			Other Nuts	-1.549	
			Mixed Nuts	-1.778	
Lerner (1959)	Single Equation Seemingly unrelated regression	Annual time – series 1922-1955	Seedling pecans	-2.729	
			Improved pecans	-3.442	
			Pecans	-1.188	
			Walnuts	-1.803	
			Filberts	-23.042	
			Almonds	-0.863	
				(Linear Function Form)	(Double Logarithmic)
Dhaliwal (1972)	Single Equation	Annual time-series 1922-1955	Pecans	-0.909	-0.856
			Walnuts	-0.286	-0.420
			Filberts	-1.926	-0.891
			Almonds	-0.548	-0.888
				(Single Equation)	(Seemingly Unrelated Regression)
Russo, Green, and Howitt (2008)	Single Equation Seemingly unrelated regression	Annual time-series 1970-2001	Almonds	−0.480 to -0.350[a]	-0.140
			Walnuts	−0.266 to -0.284	-0.200
Asci and Devadoss (2021)	General Differential Demand System	Annual time-series 1996-2018	Almonds	-0.12	
			Pistachios	-0.33	
			Walnuts	-0.16	
			Pecans	-0.08	
			Hazelnuts	-1.29	

[a] The range of estimates is due to different functional forms, including linear, double log, and Box-Cox specifications. Source: Compilations from the authors.

Compensated own-price and cross-price elasticities are exhibited for each nut category in Table 7. The semi-LA/QUAIDS model satisfies the negativity condition of compensated demands. Of the 72 estimated compensated cross-price elasticities, 44 were positive, indicative of net substitutes, and 28 were negative, indicative of net complements. We summarize the findings concerning the substitutability and complementarity of peanuts and tree nuts in Table 8. The respective substitutes and complements are arranged based in the order of the magnitude of the compensated cross-price elasticities. This ordering serves to identify the most likely substitutes/complements with respect to the set of nut products. For example, almonds and cashews are the top two substitutes for peanuts, pecans, and mixed nuts, whereas mixed nuts and peanuts are the top two substitutes for almonds, cashews, macadamias, and other nuts. Pecans and peanuts are the top two substitutes for walnuts, and almonds and other nuts are the top two substitutes for pistachios.

Expenditure and Income Elasticities

As expected, all expenditure elasticities were positive and statistically different from zero. As shown in Table 6, pistachios had the highest expenditure elasticity, 1.33, while walnuts had the lowest expenditure elasticity, 0.78. Cashews, macadamias, pistachios, and mixed nuts were more sensitive to changes in the total expenditure of nuts products than were peanuts, pecans, almonds, walnuts, and other nuts. Using equation (19), calculated income elasticities varied from 0.50 to 0.85, indicating that peanuts and tree nuts were necessities.

In Table 9, we provide a comparison of our results from those in the extant literature. Only four previous studies dealt with demand interrelationships of peanuts and tree nuts. As stated previously, these studies are not up-to-date regarding data used and models employed. Our work is more current compared to these studies in terms of the use of more recent data and the use of a more sophisticated demand systems model. Comparisons with past studies were only possible for pecans, almonds, pistachios, and walnuts. Our estimates of the own-price elasticities of pecans, almonds, and walnuts were in most cases larger than those provided in the extant literature. A richer delineation of tree nut products likely is responsible for this finding as well as the growing market and expansion of the domestic industry in terms of volume and variety.

Concluding Remarks

We utilized the semi-LA/QUAIDS model to address the demand for various nut products in the United States. Owing to different types of data, time periods, and modeling techniques, our results regarding own-price and cross-price elasticities differed from previous studies. Importantly, our findings offer insights to processors and retailers regarding pricing strategies. To illustrate, due to the elastic demand for peanuts and most tree nuts, reducing price is the appropriate strategy to increase revenue, holding all other factors invariant. However, because of the inelastic demand for walnuts and pistachios, raising prices for these nuts is the recommended strategy to increase revenue in the short run.

Estimates of income elasticities revealed that peanuts and tree nuts are necessities. As such, if the U.S. economy continues to grow, all other factors invariant, the demand for peanuts and tree nuts indeed will shift to the right. Nevertheless, changes in household income are not likely to have sizeable impacts on at-home consumption of peanuts and tree nuts. To illustrate: If household income increases by 2%, then quantities purchased of walnuts and pistachios will increase by 1% and 1.7%, respectively. Income elasticities, like own-price elasticities, are important to all stakeholders in the nut industry, especially nut purveyors and retailers concerning category management.

Although substitutability among nut products was far more common, complementarity among nut products also was evident. Information concerning the substitution and complementary patterns among peanuts and tree nuts is important strategically for stakeholders in the nut market from a competitive intelligence standpoint. For example, the California Walnut Board should keep tabs on the American Pecan Council given that pecans were identified as the top-most substitute for walnuts. In sum, with knowledge of the estimated own-price, cross-price, and income elasticities, nut purveyors and retailers will be able to more precisely monitor and measure changes in quantities purchased of peanuts and tree nuts which, in turn, will lead to improvements in inventory and procurement planning.

A limitation of our analysis concerns the implicit assumption of the weak separability of peanuts and tree nuts from other snack products. Additionally, although the semi-LA/QUAIDS model accounts for price, total expenditure, and seasonality, other explanatory factors were excluded from the analysis. Branded and generic advertising expenditures were not included in this analysis due to the unavailability of monthly data over the period 2004 through 2015. Despite the omission of these additional explanatory variables, these factors were part of the error terms in the demand system. Because of the use of the iterative SUR estimation procedure, these omitted variables were implicitly accounted for in the analysis.

Future work will focus on a household-level analysis instead of a market-level analysis to obtain a micro-perspective viewpoint. In this way, censored demand models such as the Exact Affine Stone Index Marshallian Demand system could be estimated to account for the heterogeneity of household purchases of peanuts and tree nuts incorporating socio-demographic factors such as age, household size, region, education, and ethnicity. Despite the somewhat dated time frame of our analysis, we, nevertheless, provide a detailed update of the demand interrelationships among peanuts and various tree nuts currently lacking in the extant literature. Importantly, too, our analysis then serves as a baseline for future studies. Despite these limitations, our work unquestionably adds to the economic literature concerning the nuts industry.

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Appendix

Year	Peanuts	Pecans	Almonds	Cashews	Walnuts
2004	53%	24%	27%	36%	28%
2005	54%	23%	28%	36%	29%
2006	53%	24%	30%	36%	30%
2007	50%	24%	31%	35%	28%
2008	48%	24%	34%	34%	27%
2009	48%	24%	35%	32%	30%
2010	48%	22%	35%	32%	28%
2011	48%	21%	38%	29%	27%
2012	46%	21%	38%	27%	26%
2013	46%	23%	36%	28%	25%
2014	46%	22%	33%	28%	23%
2015	43%	20%	26%	24%	22%
Year	**Macadamias**	**Pistachios**	**Mixed Nuts**	**Other Nuts**	**Total Nuts**
2004	3%	15%	34%	24%	86%
2005	3%	13%	33%	23%	86%
2006	4%	12%	33%	24%	86%
2007	3%	15%	32%	25%	85%
2008	3%	16%	31%	24%	85%
2009	3%	14%	31%	23%	85%
2010	3%	16%	30%	22%	85%
2011	2%	23%	30%	23%	85%
2012	2%	26%	29%	23%	84%
2013	2%	23%	28%	23%	84%
2014	2%	20%	27%	23%	83%
2015	2%	17%	23%	20%	80%

Source: Nielsen Homescan Panel 2004-2015, and calculations by the authors.

The annual market penetration covering the years 2004 through 2015 was calculated by dividing the number of households that purchased each respective nut by the total number of households in the Nielsen Homescan Panel for each year. We adjusted per household purchases and expenditures of peanuts and tree nuts by multiplying the annual market penetration for each respective nut category.