The Taste for Variety: Demand Analysis for Nut Products in the United States

by

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Abstract

The purpose of this study is to augment the classical demand model with consumer's variety-seeking behavior using 2004-2014 weekly Nielsen scanner data for nut products. We introduce an index variable of taste for variety into the Quadratic Almost Ideal Demand System model with pre-committed quantities. Results show that consumers do respond to the price of nut products since the pre-committed quantities only account for 10% of total consumptions. Consumers purchase more tree nut products while seeking variety, including pecan, walnut, and pistachio, and demand interrelationships among nut products change after allowing consumers to compensate through income.

Key words: Taste for variety, Nut products, Nielsen data, Demand analysis

JEL: D11, D12

1. Introduction

Nuts provide high energy and contain more dietary fiber, vitamins, minerals and unsaturated fat. About one-third of Americans consumes nuts on a regular basis. The annual per capita consumption of nuts in the United States has been growing drastically: it reached 4.2 pounds in 2014, up from 1.7 pounds in 1967 (Figure 1). Tree nuts and peanuts are consumed in the form of snacks, where consumers look for variety such as flavor and nutrients. One interesting aspect of nut products marketing is the presence of category called "mixed nuts". Moreover, the consumption of nut products with mixed packaging rank the third place following the consumptions of peanuts and almonds, in which firms recognize the existence of consumer's variety-seeking behavior by marketing on it. However, there are few studies on demand for nut products present in the extant literature, as well as variety-seeking behavior as it affects consumer's demand. This study proposes to augment the classical demand model with consumer's variety-seeking behavior using 2004-2014 weekly Nielsen scanner data for nut products. We incorporate an index variable of taste for variety into the Quadratic Almost Ideal Demand System model by following Drescher, Thiele, and Weiss (2008). Consumption of mixed packaging is a strong signal of taste for variety. Introducing such an index will help delineate variety-seeking behavior as it affects expenditure shares of different nut products consumed. Moreover, estimated elasticities from simple demand systems may be biased under the situation of consumers such behaviors. Moreover, we incorporate the variety index into QUAIDS model with pre-committed quantities that are to be estimated in order to get unbiased elasticities estimation (Bollino (1987)).

This study is proceeded as following. In the first section, previous studies that related to tree nuts and peanuts demand along with tastes for variety are reviewed. In the second section, the generalized quadratic AIDS model with variety index used for estimation is presented and derived. We discussed data that used in estimation and provided descriptive statistics in the third section. In the following section, results are reported and discussed.

2. Literature Review

In extant literature, there are few studies that documented demand interrelationships of tree nuts. In a Giannini Foundation Mimeographed report, Lee (1950) examined the influence of walnuts, filberts, and pecans on the price-quantity relationship for almonds by including an index of the prices of those tree nuts product. However, all of the previous studies did not directly examined the demand interrelationships among tree nuts. We believe that Lerner (1959) made the first attempt investigating the characteristics of demand for pecans at the farm level by analyzing the demand interrelationships between improved pecans and seedling or native pecans, among pecans and other tree nuts, in which the estimated own-price elasticities are quite elastic, -2.73 for seedling pecans and -3.44 for improved pecans, and complement between pecans and walnuts, substitution between pecans and filberts, pecans and almonds, walnuts and almonds are found. Dhaliwal (1972) made another attempt in his dissertation to examine demand interrelationships by assuming and dividing eight tree nuts into categories of substitutes, complements, and independents with findings of substitutes and complementary among them. After Dhaliwal, no study that could be tracked and examined demand interrelationships of tree nuts and peanuts directly. Wells, Miller, and Thompson (1986) contradicted previous studies estimating a flexible farm level demand for pecans by incorporating a time series of pecans stock. Alternatively, most of studies looked at the prices of tree nuts and peanut. Florkowski (1988) forecasted the price of pecans during harvest season but did not consider the demand interrelationships between pecans and other nut products. Shafer (1989) addressed the overestimated pecan crop forecast and pointed out early season crop estimates provided a better explanation of price behavior than postseason revised production data. Florkowski, Lai et al. (1997) forecasted the price of pecans by considering the cointegration between prices of pecans and other tree nuts and they found that taking substitutes effect into account increased the accuracy of forecasting. Florkowski* and Sarmiento (2005) utilized a spatial analysis to investigate the factors that affect the price received by pecan growers and identified the linkages between the price of in-shell pecans and the characteristics of the orchard. Ibrahim, Florkowski et al. (2009) forecasted the U.S. tree nuts prices over the period 1992-2006 by using a vector auto regression model with Johansen cointegration technique, in which there is little evidence of long run relationship among the prices of pecan, walnut, and almond.

Since most of tree nuts in Unite States are produced in California, researchers have looked at this market specifically. Green (1999) documented the demand of almond in California by taking into account of factors, including prices of other tree nuts, per capita income of consumers, demographics, social and economic factors. Crespi and Chacon-Cascante (2004) used a case study to analyze the market power for U.S. almonds in both local and international markets and found that market power of the Almond Board of California is significantly less than the expected of a profit-maximizing cartel. Russo, Green, and Howitt (2008) estimated domestic own-price, cross-price and income elasticities of demand and estimated price elasticities of supply for several California commodities, including almonds, walnuts, alfalfa, cotton, rice, and tomatoes by utilizing Box-Cox specification and the non-linear almost ideal demand system. In this study, they found inelastic own-price elasticities for almonds and walnuts and no substitution between almond and walnut as well.

The following studies focused on the promotion of tree nuts in both local and international markets. Even though these studies did not investigate the demand of nuts directly, they looked at the demand at aggregate level and provided insights about how nuts markets look like in national and international level. Halliburton and Henneberry (1995) conducted a case study evaluating federal government's programs for U.S. almond export in five countries of the Pacific Rim area with findings that promotions are not effective in South Korea and Singapore but effective in Japan, Taiwan, and Hong Kong. Onunkwo and Epperson had a series of studies that examined the impact of U.S. export promotion programs on the foreign demand of walnuts (2000), pecans (2000), and almond (2001) by estimating marginal return of promotion expenditures. Florkowski and Park (2001) investigated pecans demand by estimating a generalized Heckman model of consumers' purchases decisions and they found promotion programs could help stabilize and maintain the demand of pecans. Moore et al. (2009) valuated the economic effectiveness of the Texas Pecan Checkoff Program, which confirmed its success on increasing sales of improved varieties of Texas pecans but not on sales of native varieties.

Regarding studies related to taste for variety, Jackson (1984) built hierarchic demand systems to differentiate consumers' behavior when existing purchasing and potential demand with empirical results of needs for variety. Lancaster (1990) conducted a survey that documented existing economice theory of product variety since 1975, including single product and multiple products market. Based on the monopolistic competiton framework of the Dixit-Stiglitz-Spence, Benassy (1996) revisited the link between market structure and taste for variety and provided a more realistic definiton of it. Drescher, Thiele, and Weiss (2008) utilized a hedonic method to model taste for variety by estimating a variety index and product attributes on households' consumptions.

In a summary, no studies used panel data analysis, demand system analysis and scanner data to address demand interrelationships among tree nuts and peanuts by incorporating tast for variety.

3. Methodology

In this study, we used a method called Generalized Quadratic Almost Ideal Demand system with Entropy Index. First, we followed Almost Ideal Demand system that was first introduced by Deaton and Muellbauer (1980) and modified by Banks, Blundell, and Lewbel (1997) later by adding a quadratic terms to address the nonlinear Engel curve. The model begins with an indirect utility function given by equation (1).

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

After setting $\lambda(\boldsymbol{p})$ to be zero, the equation (2) could be derived, and $\ln a(\boldsymbol{p})$ has a translog form,

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

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

where p_i is the price for i product, and $b(\boldsymbol{p})$ is the Cobb-Douglas price aggregator.

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

where $\sum_i \lambda_i = 0$

Then the budge share w_i is a function of price $\ln p$ and expenditure $\ln m$, given by equation

(5).

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

However, this model does not take pre-committed consumptions into account. Second, we followed Bollino (1987), in which estimating elasticities without considering committed quantities would yield bias results.

$$(6) \quad w_i = \frac{c_i p_i}{m} + (1 - \frac{\sum_i c_i p_i}{m})(\alpha_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln [\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}] + \frac{\lambda_i}{b(\boldsymbol{p})} \ln [\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}]^2)$$

where $c_i p_i$ is the pre-committed consumptions which is defined as the ones that consumers purchased before considering the price. Next, we also include Entropy Index into the above equation in order to capture consumers' taste for variety (Drescher, Thiele, and Weiss (2008)). The index enters into the model as a part of constant terms,

$$(7) \quad \alpha_i = \rho_{i0} + \rho_i E$$

where E is the Entropy Index, $E = \sum_{i=1}^{N} s_i \; ln \; s_i$, where $s_i = q_i/Q$, q_i is the quantity consumed for each category i, Q is the total quantity consumed for all category.

After incorporating the index, we have expenditure share equation as,

$$(8) \quad w_i = \frac{c_i p_i}{m} + (1 - \frac{\sum_i c_i p_i}{m})(\rho_{i0} + \rho_i \sum_{i=1}^{N} s_i \; ln \; s_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln [\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}] + \frac{\lambda_i}{b(\boldsymbol{p})} \ln [\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}]^2)$$

Before estimating the equation (5), there are a few restrictions that need to apply. They are adding up, homogeneity, and Slutsky symmetry given in equation (9).

$$(9) \quad \sum_{i=1}^{n} \alpha_i = 1, \quad \sum_{i=1}^{n} \beta_i = 0, \quad \sum_{j=1}^{n} \gamma_{ij} = 0, \quad \sum_{i=1}^{n} \lambda_i = 0, \quad \text{and} \quad \gamma_{ij} = \gamma_{ji}$$

In order to estimate elasticities from previous model, differentiate equation (5) with respect to price term and expenditure term, and the expenditure elasticities are given as following,

$$(10) \quad \varepsilon_i = 1 - \frac{c_i p_i}{m w_i} + \frac{\sum_i c_i p_i}{m w_i}(\rho_{i0} + \rho_i \sum_{i=1}^{N} s_i \, ln \, s_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln [\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}] + \frac{\lambda_i}{b(\boldsymbol{p})} \ln [\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}]^2) + (\frac{1}{w_i} - \frac{\sum_i c_i p_i}{m w_i})(\beta_i + \frac{2\lambda_i}{b(\boldsymbol{p})}\{\ln[\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}]\})$$

The uncompensated price elasticities are,

$$(11) \quad e_{ij}^{u} = (\frac{1}{w_i} - \frac{c_i p_i}{m w_i})\left(\gamma_{ij} - \mu_i(\rho_{j0} + \rho_j \sum_{i=j}^{N} s_j ln \, s_j + \sum_k \gamma_{jk} \ln P_k) - \frac{\lambda_i \beta_j}{b(\boldsymbol{p})}\{\ln [\frac{m - c_i p_i}{a(\boldsymbol{p})}]\}^2\right) - \delta_{ij}$$

where δ_{ij} is the Kronecker delta. And the compensated price elasticities could be derived from Slutsky equation, $e_{ij}^{c} = e_{ij}^{u} + \varepsilon_i w_j$.

There issues needs to be addressed before estimation. First, since we utilized time series data, autocorrelations need to be controlled.

$$(12) \quad w_{it} = \sum_k \rho_k w_{it-k} + \frac{c_i p_{it}}{m_t} + (1 - \frac{\sum_i c_i p_{it}}{m_t})(\rho_{i0} + \rho_i \sum_{i=1}^{N} s_{it} \, ln \, s_{it} + \sum_{j=1}^{n} \gamma_{ij} \ln p_{jt} + \beta_i \ln [\frac{m_t - \sum_i c_i p_{it}}{a(\boldsymbol{p})_t}] + \frac{\lambda_i}{b(\boldsymbol{p})_t} \ln [\frac{m_t - \sum_i c_i p_{it}}{a(\boldsymbol{p})_t}]^2) - \sum_k \rho_k \Bigg(\frac{c_i p_{it-k}}{m_{t-k}} + (1 - \frac{\sum_i c_i p_{it-k}}{m_{t-k}})(\rho_{i0} + \rho_i \sum_{i=1}^{N} s_{it-k} \, ln \, s_{it-k} + \sum_{j=1}^{n} \gamma_{ij} \ln p_{jt-k} + \beta_i \ln [\frac{m_{t-k} - \sum_i c_i p_{it-k}}{a(\boldsymbol{p})_{t-k}}]$$

$$+ \frac{\lambda_i}{b(\boldsymbol{p})_{t-k}} \ln \left[\frac{m_{t-k} - \sum_i c_i p_{it-k}}{a(\boldsymbol{p})_{t-k}}\right]^2) \Bigg) + \varepsilon_{it}$$

where k is the number of lag terms. The derivation could be found in appendix.

The second problem is that total expenditure in QUAIDS model suffer from endogeneity, in which quantity and price are used to calculate it. We forecasted the total expenditures and replaced the original data (Capps Jr et al. (1994), Dharmasena and Capps (2012)). Regarding the forecast technique, a simple Vector Autoregressive (VAR) was used, in which total expenditure and income variables are correlated with each other.

$$(13) \quad m_t = \sigma_0 + \sigma_1 I_{t-1} + \sigma_2 I_{t-2} + \cdots + \phi_{1t}$$

$$(14) \quad I_t = \upsilon_0 + \upsilon_1 m_{t-1} + \upsilon_2 m_{t-2} + \cdots + \phi_{2t}$$

where I_t is income at time t. After estimating this VAR model, we forecasted statically the within sample m_t with $\hat{m}_t$, and plug them back into QUAIDS model.

The last issue is that since this function form is highly non-linear, in order to simplify the estimation, we linearized the two price indexes. First, we replace $a(\boldsymbol{p})$ and $b(\boldsymbol{p})$ with following formulas,

$$(15) \quad a(\boldsymbol{p}) = \sum_i w_{it-1} ln\ p_i$$

$$(16) \quad b(\boldsymbol{p}) = \sum_i (w_{t-1} - w_{t-2})(ln\ p_{it-1} - ln\ p_{it-2})$$

Then we defined the Generalized Quadratic Almost Ideal Demand System with Entropy Index by incorporating equations (9), (12), (15), and (16).

4. Data

The data used in this study are 2004 to 2014 household level data from Nielsen Homescan. According to research question of this study, we categorized nut products based on different packaging in the first step, then divide them into subgroup of peanuts and tree nuts, which are based on product module code and product's description provided by Nielsen data. The eight categories are: 1) peanuts, 2) pecans, 3) almonds, 4) cashews, 5) walnuts, 6) pistachios, 7) mix, 8) other nuts. Other nuts consist of nut products like, nuts topping, pumpkin nuts, filbert, sunflower seeds, etc.

To meet the needs of this study, we derived total quantity (oz) from quantity and amount data that are reported by Nielsen. Also, total price paid as expenditure is reported which is used to calculate unit price (dollar/oz) of each category. After computing total quantity, total expenditure and unit price, we aggregated the data by weekly observation and nut categories for all household that purchases nut products.

Descriptive Statistics

Table 1 provides descriptive statistics for weekly aggregated level data (581 weeks from 2004 to 2014). The price of different category is reasonable since peanut is the cheapest ($0.13) and pecan is the highest ($0.47). Expect for peanut and pecan, all of the other tree nut products have similar price, range for $0.31 to $0.35. The most purchased product is peanut, followed by almond and mix according to total quantities and total expenditure. Surprisingly, the total expenditures of mixed packaging rank at the third place, in which consumers do have variety-seeking behavior facing peanut and tree nuts products.

Table 1 here

5. Results

Estimated Price, Expenditure, Entropy Index, and Pre-committed Coefficients

The estimated coefficients of demand systems that consists of seven share equations are shown in Table 2, and model fitness is shown in Table 3. The estimation is done in SAS by using iterated seemingly unrelated regression estimation. After 56 iterations, our model met the convergence requirement, that is 0.00001. According to R^2 and adjusted R^2, most of the equations fitted pretty well, range from 0.61 to 0.98. The autocorrelation issues are controlled after incorporating lag terms in equation (12), and the optimal number of lag, namely k, is 2 across all seven equations. In order to find the optimal k, we estimated the demand system many times with different k each time, in which both $r1$ and $r2$ are significant at 1% significance level. Regarding the parameters of demand system, 12 out of 36 γ_{ij} are not significant, all pre-committed ones are significant, 2 out of 8 λ_i quadratic terms are significant, all of α_i are significant under 5% level, half of β_i are not significant, and 3 out of 8 Entropy Index parameters are not significant. We calculated the percentage of pre-committed quantities on total for each category. As shown in Table 4, the percentage of pre-committed quantities varies from 8% to 16%. Regarding consumers' variety seeking behavior, for these Entropy Index coefficients that are significant, consumer will purchase more of nuts products while satisfying taste for variety except for peanuts.

Table 2 &3 &4 here

Expenditure Elasticities

The estimated expenditure elasticities are reported in Table 5. All of elasticities are positive and significant at 1% level, range from 0.85 to 1.05. Almond, cashew, and other are considered as necessity since their expenditure elasticities are lower than unity, in which means one percent change in total expenditure for nuts product would yield less than one percent change in them. However, pecan, walnut, and pistachio are luxury goods for expenditure elasticities that are above unity. One percent change in total expenditure will cause more than one percent change in the purchases of pecan, walnut and pistachio. The expenditure elasticities of peanut and mixed packaging are exactly one.

Table 5 here

Uncompensated Price Elasticities

The estimated uncompensated price elasticities are reported in Table 7, including eight own-price elasticities and fifty-six cross-price elasticities. 40 out of 64 elasticities are statistically significant, in which own-price elasticities range from -0.30 to -1.49. Based on economic theory, the price elasticities we estimated here is when consumers are not allowed to compensate through income facing price change of particular product. Peanut, pecan and other are inelastic since their estimated own-price elasticities are below one, in which one percent change of price will cause less than one percent change in quantities purchased that consumers are not sensitive to price change. The other six products are more elastic as the estimated own-price elasticities are bigger than one that one percent change of price will yield more than one percent change in consumptions. Unsurprisingly, there are substitution relationship between some products. According to estimated cross-price elasticities, almond and pecan, cashew are net substitutes. Meanwhile, some complementary relationship evidences are also found, for example, peanut with all of other products. We summarized all of interrelationships among peanut and tree nut products in Table 8.

Table 6 & 8 here

Compensated Price Elasticities

As shown in Table 8, 55 out of 64 price elasticities are significant, including all eight own-price elasticities. Unlike uncompensated demand, we estimated the elasticity allowing consumers to compensate their consumptions by income while facing price change. Five out of eight own-price elasticities are below unity, in which cashew and mixed packaging become inelastic compared with uncompensated estimates. Compared with compensated price elasticity, some of the demand interrelationships flipped after allowing consumers to compensate through income while facing price changes. The full demand interrelationships are shown in Table 9. As shown, peanut is considered as complements with almond and cashew in uncompensated demand, and becomes substitute with them in compensated demand. Also, other nuts do not have neither complementary nor substitute relationship with all other products except for peanut according to estimated uncompensated elasticities, but become substitution for almond, cashew, walnut, pistachio, and mixed packaging. In a word, whether consumers could compensate consumptions with income does make a difference to determine whether they are sensitive to price change and switch between different products.

Table 7 & 9 here

6. Conclusions

In extant literature, very few studies ever documented demand analysis of peanuts and tree nuts products, including estimating expenditure and price elasticities. The purpose of this study is to explore consumers' variety-seeking behaviors by utilizing nuts market data. Based on Nielsen market household-level data, we constructed a time series QUAIDS model by incorporating pre-committed quantities and Entropy Index. The major findings of this study are as following. First, according to estimated pre-committed quantities, the average percentage is around 10 % which means consumptions of nuts products that are not sensitive to their prices only account for a small amount. Consequently, utilizing demand analysis to address demand interrelationships among nuts products are meaningful since consumers do respond to price change of 90% of total consumptions. Second, the results showed that consumers do seek variety when facing tree nuts products, in which the evidence comes from total expenditure of mixed packaging and estimated Entropy Index coefficients. According to the estimated entropy index coefficients, consumers will purchase more of pecan, almond, walnut, pistachio, and mixed packaging when satisfying taste for variety. Regarding elasticities estimated, compared with estimation of Lerner (1959), own-price elasticities are much lower since consumptions of nuts changed and increased after so many years. In addition, more than four different products are considered as luxury good based on the estimated expenditure elasticities, including pecan. One interesting about pecan we found in this study is that even pecan is considered as a luxury good according to expenditure elasticity, consumers who purchase pecan is not sensitive to the price change of it. The demand interrelationships among nuts products are summarized separately in Table 8 and 9 for uncompensated and compensated demand. Allowing consumers to compensate consumption through income do make a difference to delineate consumers' behavior. Meanwhile, there are a few limitations of this study that could be extended in future studies. First, even though we utilized household-level data, we aggregated all of them and structured a time series model, in which we avoided censoring problem that might lead to biased results. Second, we only used one type of index to address taste for variety and we did not get a very ideal results that the coefficient of Entropy Index on mixed packaging should be larger than others. In future studies, different type of index could be tried and incorporated in demand analysis.

Appendix

Reduced Form

$$w_{it} = f(x_{it}, \beta) + v_{it}$$

$$v_{it} = \rho v_{it_1} + \varepsilon_{it}$$

$$w_{it} = \rho w_{it-1} + f(x_{it}, \beta) - \rho f(x_{it}, \beta) + \varepsilon_{it}$$

$$w_{it} = \sum_k \rho_k w_{it-1} + f(x_{it}, \beta) - \sum_k \rho_k f(x_{it-k}, \beta) + \varepsilon_{it}$$

$$\begin{aligned} w_{it} \ = & \sum_k \rho_k w_{it-k} + \frac{c_i p_{it}}{m_t} \ + \ (1 - \frac{\sum_i c_i p_{it}}{m_t})(\rho_{i0} + \rho_i \sum_{i=1}^{N} s_{it} \ ln \ s_{it} \ + \ \sum_{j=1}^{n} \gamma_{ij} \ln p_{jt} \\ & + \beta_i \ln [\frac{m_t - \sum_i c_i p_{it}}{a(\boldsymbol{p})_t}] \ + \ \frac{\lambda_i}{b(\boldsymbol{p})_t} \ln [\frac{m_t - \sum_i c_i p_{it}}{a(\boldsymbol{p})_t}]^2) - \sum_k \rho_k \Bigg(\frac{c_i p_{it-k}}{m_{t-k}} \\ & + \ (1 - \frac{\sum_i c_i p_{it-k}}{m_{t-k}})(\rho_{i0} + \rho_i \sum_{i=1}^{N} s_{it-k} \ ln \ s_{it-k} \ + \ \sum_{j=1}^{n} \gamma_{ij} \ln p_{jt-k} + \beta_i \ln [\frac{m_{t-k} - \sum_i c_i p_{it-k}}{a(\boldsymbol{p})_{t-k}}] \\ & + \ \frac{\lambda_i}{b(\boldsymbol{p})_{t-k}} \ln [\frac{m_{t-k} - \sum_i c_i p_{it-k}}{a(\boldsymbol{p})_{t-k}}]^2) \Bigg) + \varepsilon_{it} \end{aligned}$$

Elasticities

In order to calculate elasticity, first, differentiate the share equations with respect to expenditure and price,

$$\begin{aligned} \mu_i \ = \frac{\partial w_i}{\partial ln \ m} = & - \ \frac{c_i p_i}{m} \ + \ \frac{\sum_i c_i p_i}{m}(\rho_{i0} + \rho_i \sum_{i=1}^{N} s_i \ ln \ s_i \ + \ \sum_{j=1}^{n} \gamma_{ij} \ln p_j \ + \beta_i \ln [\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}] \\ & + \ \frac{\lambda_i}{b(\boldsymbol{p})} \ln [\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}]^2) \ + \ (1 - \frac{\sum_i c_i p_i}{m})(\beta_i \ + \ \frac{2\lambda_i}{b(\boldsymbol{p})} \{\ln[\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}]\}) \end{aligned}$$

$$\mu_{ij} = \frac{\partial w_i}{\partial ln \ p_j} = - \frac{c_j p_j}{m}(\rho_{i0} + \rho_i \sum_{i=1}^{N} s_i \ ln \ s_i \ + \ \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln [\frac{m - \sum_i c_i p_i}{a(\boldsymbol{p})}]$$

$$+\ \frac{\lambda_i}{b(\boldsymbol{p})}\ln\left[\frac{m-\sum_i c_i p_i}{a(\boldsymbol{p})}\right]^2) + (1-\frac{\sum_i c_i p_i}{m})(\gamma_{ij}+\beta_i(\frac{-c_j p_j}{m-\sum_i c_i p_i}-\alpha_j-\sum_k \gamma_{jk} lnP_k)$$

$$-\frac{2\lambda_i}{b(\boldsymbol{p})}\ln\left[\frac{m-\sum_i c_i p_i}{a(\boldsymbol{p})}\right](\alpha_j+\sum_k \gamma_{jk} lnP_k)-\frac{\lambda_i\beta_j}{b(\boldsymbol{p})}\ln\left[\frac{m-\sum_i c_i p_i}{a(\boldsymbol{p})}\right]^2)$$

then, the expenditure elasticities are,

$$\varepsilon_i = \mu_i/w_i + 1$$

uncompensated price elasticities are,

$$e^u_{ij} = \frac{\mu_{ij}}{w_i} - \delta_{ij}$$

and compensated price elasticities are,

$$e^c_{ij} = e^u_{ij} + \varepsilon_i w_j$$

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Figures

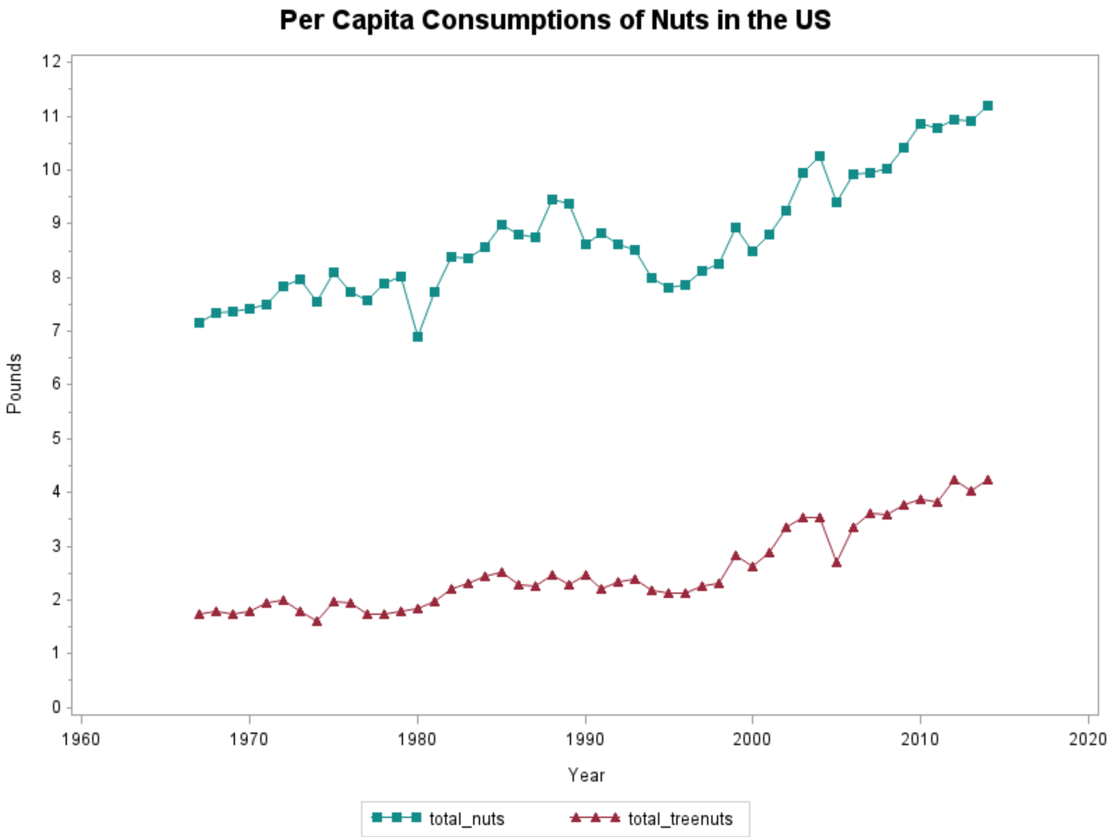

Figure 1. Per Capita Consumptions of Nuts in the United States Source: USDA

Tables

Table 1. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Expenditures					
Peanut	581	7346.67	1883.34	394.57	16210.75
Pecan	581	3022.03	2450.28	75.43	13603.96
Almond	581	6303.68	2259.04	168.07	14047.38
Cashew	581	5483.20	1476.27	282.75	13321.13
Walnut	581	3710.53	2021.78	75.58	11126.83
Pistachio	581	3432.19	2138.87	36.68	12144.81
Mix	581	6283.04	2050.37	313.29	17685.94
Other	581	2390.08	704.27	110.37	5529.44
Prices					
Peanut	581	0.13	0.01	0.10	0.17
Pecan	581	0.47	0.07	0.26	0.63
Almond	581	0.35	0.04	0.25	0.46
Cashew	581	0.32	0.07	0.18	0.45
Walnut	581	0.34	0.08	0.20	0.50
Pistachio	581	0.33	0.10	0.19	0.55
Mix	581	0.31	0.05	0.22	0.42
Other	581	0.25	0.03	0.19	0.33
Quantities					
Peanut	581	55901.04	12143.49	3511.27	124102.80
Pecan	581	6484.53	5302.07	241.00	27609.00
Almond	581	18025.06	6620.51	424.25	44106.71
Cashew	581	17282.15	4318.04	1016.25	39187.45
Walnut	581	10831.56	5633.07	237.25	33735.70
Pistachio	581	9661.43	4434.88	140.25	30507.90
Mix	581	20448.76	6535.32	1298.89	59167.62
Other	581	9504.61	2390.84	501.63	19165.52

Table 2. Demand System Parameter Estimates

Parameters		Estimate	t Value	P-value
Gamma	gpeanutpeanut	0.14	31.00	0.00
	gpeanutpecan	-0.03	-7.67	0.00
	gpeanutalmond	-0.02	-4.72	0.00
	gpeanutcashew	-0.01	-3.08	0.00
	gpeanutwalnut	-0.03	-6.53	0.00
	gpeanutpistachio	-0.02	-5.39	0.00
	gpeanutother	-0.02	-8.50	0.00
	gpeanutmix	0.00	0.12	0.91
	gpecanpecan	0.02	1.30	0.20
	gpecanalmond	0.06	5.86	0.00
	gpecancashew	-0.03	-3.29	0.00
	gpecanwalnut	0.00	-0.15	0.88
	gpecanpistachio	0.01	1.53	0.13
	gpecanother	0.00	0.41	0.68
	gpecanmix	-0.03	-3.62	0.00
	galmondalmond	-0.09	-5.79	0.00
	galmondcashew	0.03	3.22	0.00
	galmondwalnut	0.02	2.04	0.04
	galmondpistachio	-0.03	-3.44	0.00
	galmondother	0.00	-0.47	0.64
	galmondmix	0.04	3.90	0.00
	gcashewcashew	-0.03	-2.02	0.04
	gcashewwalnut	0.03	3.66	0.00
	gcashewpistachio	0.02	2.32	0.02
	gcashewother	0.00	0.30	0.76
	gcashewmix	-0.01	-1.40	0.16
	gwalnutwalnut	-0.07	-5.86	0.00
	gwalnutpistachio	0.03	4.53	0.00
	gwalnutother	0.01	1.48	0.14
	gwalnutmix	0.01	0.98	0.33
	gpistachiopistachio	-0.03	-3.35	0.00
	gpistachioother	0.00	-0.04	0.97
	gpistachiomix	0.02	2.61	0.01
	gotherother	0.01	3.25	0.00
	gothermix	0.00	0.17	0.87
	gmixmix	-0.02	-1.87	0.06

Pre-committed	cpeanut	5658.97	7.81	0.00
	cpecan	1019.05	2.81	0.01
	calmond	1606.20	3.23	0.00
	ccashew	1369.05	3.19	0.00
	cwalnut	1662.46	5.70	0.00
	cpistachio	982.49	3.68	0.00
	cother	1101.86	3.38	0.00
	cmix	2028.94	4.15	0.00
Lambda	lampeanut	0.00	-0.58	0.56
	lampecan	0.00	-0.53	0.60
	lamalmond	0.00	-0.82	0.41
	lamcashew	0.00	1.81	0.07
	lamwalnut	0.00	-0.34	0.73
	lampistachio	0.00	2.65	0.01
	lamother	0.00	-2.55	0.01
	lammix	0.00	-0.86	0.39
Alpha	apeanut	1.22	33.33	0.00
	apecan	-0.84	-8.94	0.00
	aalmond	0.55	5.79	0.00
	acashew	0.24	3.33	0.00
	awalnut	-0.41	-6.88	0.00
	apistachio	-0.11	-1.94	0.05
	aother	0.16	3.71	0.00
	amix	0.18	2.61	0.01
Beta	bpeanut	0.00	0.62	0.54
	bpecan	0.03	4.09	0.00
	balmond	-0.03	-4.16	0.00
	bcashew	-0.01	-1.50	0.14
	bwalnut	0.01	3.12	0.00
	bpistachio	0.01	1.50	0.14
	bother	-0.01	-3.10	0.00
	bmix	0.00	-0.70	0.48
Entropy Index	rpeanut	-0.50	-48.97	0.00
	rpecan	0.27	13.65	0.00
	ralmond	-0.03	-1.28	0.20
	rcashew	0.00	0.23	0.82
	rwalnut	0.17	12.31	0.00
	rpistachio	0.05	3.65	0.00
	rother	0.01	0.73	0.47
	rmix	0.02	1.68	0.09
Lag Terms	r1	0.59	37.39	0.00
	r2	0.28	17.63	0.00

Table 3. Model Fitness

Equation	R-Square	Adj R-Sq	Durbin Watson
Peanut	0.98	0.98	2.08
Pecan	0.86	0.86	1.74
Almond	0.77	0.76	2.02
Cashew	0.71	0.71	2.31
Walnut	0.84	0.84	1.96
Pistachio	0.92	0.92	1.77
Other	0.61	0.61	2.10

Table 4. Pre-committed Quantities

	Quantities (at means)	Pre-committed	Percentage
Peanut	55901.04	5658.97	10%
Pecan	6484.53	1019.05	16%
Almond	18025.06	1606.20	9%
Cashew	17282.15	1369.05	8%
Walnut	10831.56	1662.46	15%
Pistachio	9661.43	982.49	10%
Mix	20448.76	2028.94	10%
Other	9504.61	1101.86	12%

Table 5. Income Elasticities

Income Elasticity	Estimate	Std Err
Peanut	1.00	0.01
Pecan	1.34	0.05
Almond	0.85	0.02
Cashew	0.97	0.02
Walnut	1.09	0.03
Pistachio	1.05	0.03
Other	0.86	0.03
Mix	1.00	0.02

Table 6. Uncompensated Price Elasticities

	Peanut	Pecan	Almond	Cashew	Walnut	Pistachio	Other	Mix
Peanut	-0.30	-0.15	-0.12	-0.08	-0.14	-0.10	-0.11	-0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
Pecan	-0.48	-0.54	0.53	-0.48	-0.01	0.13	-0.05	-0.48
	(0.05)	(0.17)	(0.15)	(0.11)	(0.10)	(0.10)	(0.06)	(0.10)
Almond	-0.11	0.28	-1.35	0.21	0.07	-0.17	0.01	0.23
	(0.03)	(0.06)	(0.09)	(0.06)	(0.05)	(0.05)	(0.03)	(0.05)
Cashew	-0.09	-0.21	0.21	-1.07	0.16	0.10	0.01	-0.08
	(0.03)	(0.05)	(0.06)	(0.07)	(0.05)	(0.05)	(0.03)	(0.05)
Walnut	-0.32	0.02	0.08	0.24	-1.49	0.31	0.03	0.03
	(0.04)	(0.08)	(0.09)	(0.08)	(0.10)	(0.07)	(0.05)	(0.08)
Pistachio	-0.25	0.14	-0.38	0.16	0.35	-1.25	-0.02	0.19
	(0.04)	(0.09)	(0.10)	(0.08)	(0.08)	(0.11)	(0.05)	(0.08)
Other	-0.31	-0.02	0.03	0.05	0.07	-0.01	-0.69	0.03
	(0.04)	(0.07)	(0.08)	(0.07)	(0.06)	(0.06)	(0.06)	(0.07)
Mix	-0.01	-0.18	0.20	-0.08	0.03	0.10	0.00	-1.05
	(0.03)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.03)	(0.07)

Note: Standard deviations are provided in parenthesis

Table 7. Compensated Price Elasticities

	Peanut	Pecan	Almond	Cashew	Walnut	Pistachio	Other	Mix
Peanut	-0.09	-0.08	0.05	0.07	-0.05	-0.02	-0.04	0.16
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
Pecan	-0.21	-0.44	0.75	-0.28	0.21	0.24	0.04	-0.25
	(0.05)	(0.17)	(0.14)	(0.11)	(0.10)	(0.10)	(0.06)	(0.10)
Almond	0.06	0.34	-1.21	0.34	0.15	-0.10	0.07	0.37
	(0.03)	(0.06)	(0.09)	(0.06)	(0.05)	(0.05)	(0.03)	(0.05)
Cashew	0.10	-0.13	0.37	-0.92	0.25	0.18	0.07	0.08
	(0.03)	(0.06)	(0.06)	(0.07)	(0.05)	(0.05)	(0.03)	(0.05)
Walnut	-0.10	0.10	0.26	0.40	-1.38	0.40	0.10	0.21
	(0.04)	(0.08)	(0.09)	(0.08)	(0.10)	(0.07)	(0.04)	(0.08)
Pistachio	-0.04	0.22	-0.20	0.32	0.44	-1.16	0.05	0.36
	(0.04)	(0.09)	(0.10)	(0.08)	(0.08)	(0.11)	(0.05)	(0.08)
Other	-0.14	0.04	0.18	0.18	0.15	0.06	-0.63	0.18
	(0.04)	(0.07)	(0.08)	(0.07)	(0.06)	(0.06)	(0.06)	(0.07)
Mix	0.19	-0.11	0.36	0.07	0.12	0.18	0.07	-0.88
	(0.03)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.03)	(0.07)

Table 8. Demand Interrelationships-Uncompensated

	Peanut	Pecan	Almond	Cashew	Walnut	Pistachio	Other	Mix
Peanut		C	C	C	C	C	C	
Pecan	C		S	C				C
Almond	C	S		S		C		S
Cashew	C	C	S		S	S		
Walnut	C			S		S		
Pistachio	C		C	S	S			S
Other	C							
Mix		C	S			S		

Note: C–Complement, S–Substitute

Table 9. Demand Interrelationships-Compensated

	Peanut	Pecan	Almond	Cashew	Walnut	Pistachio	Other	Mix
Peanut		C	S	S	C		C	C
Pecan	C		S	C		S		C
Almond	S	S		S	S	C	S	S
Cashew	S	C	S		S	S	S	
Walnut	C		S	S		S	S	S
Pistachio		S	C	S	S			S
Other	C		S	S	S			S
Mix	C	C	S		S	S	S	