An Analysis of Fresh Vegetables in the Dallas-Fort Worth Metropolitan Area

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Abstract

Since 1961 world vegetable consumption and production have been increasing steadily at annual average growth rates of 3.24 % and 9.29 % respectively. Tomatoes represent the largest annual world production volume with an average share of 62% followed by carrots (13 %), lettuce (10%), cauliflower (8%), spinach (6%) and onions (2 %). The study estimates the full Almost Ideal Demand System (AIDS) and provides an in-depth analysis of fresh vegetables in the Dallas-Ft. Worth metropolitan area, which is largest market for Northeast Texas producers. The study estimates expenditure and price elasticities using AC Nielsen Homescan consumption data on carrots, cauliflowers, lettuce, onions, spinach, tomatoes, and precut salad mix. It is critical for vegetable growers and agribusinesses to understand the substitution patterns among different types of vegetables as well as current production and consumption trends at the retail level. A discussion about how various types of fresh vegetables perform at the retail level is presented. Several cases of substitutes and complements fresh vegetables were identified. Our disaggregated analysis may help producers better identify products that are highly marketable in the area. Our results may also provide insight in determining which fresh vegetables are most profitable for local producers.

Key words: demand system, disagregated analysis, fresh vegetables, elasticities

JEL codes: Q11, R21

Introduction

World vegetable production increased 483.27% from 1961 to 2013 (FAOSTAT Online Database, 2015). Tomatoes represent the largest annual world production volume for the same period with an average share of 62% followed by carrots with an average share of 13%, lettuce with 10%, cauliflower with 8%, spinach with 6%, and onions with 2% (FAOSTAT Online Database, 2015).

According to FAOSTAT Online Database (2015), from 1961 to 2013, the world's ten largest vegetable producing countries, in descending order, are China (25.26%), Spain (14.06%), United States (10.91%), Egypt (10.73%), Italy (7.69%), India (7.64%), Turkey (5.04%), Russia (4.70%), Japan (2.13%) and Mexico (1.84%). Together these ten countries account for 74.12% of the total world vegetable production. Table 1 summarizes the world's ten largest producing countries for selected vegetables.

In terms of total consumption, according to FAOSTAT Online Database (2015), from 1961 to 2013, the world's ten largest vegetable consuming countries, in descending order, are China (39.56%), India (10.13%), United States (5.97%), Russia (4.64%), Turkey (3.18%), Japan (3.00%), Italy (2.27%), Egypt (1.95%), South Korea (1.68%), and Iran (1.59%). These ten countries account for 76.48% of the total world vegetable consumption. In terms of per-capita consumption, the world's largest per-capita vegetable consuming countries are Turkey (200.18 kg/year), South Korea (174.21 kg/year), Italy (165.10 kg/year), Egypt (158.65 kg/year), China (131.60 kg/year), Iran (128.98 kg/year), Japan (116.84 kg/year), United States (111.12 kg/year), Russia (90.74 kg/year), India (52.28 kg/year).

Growing population plays a key role in the increasing demand for food. Analyzing the population growth of the G20, a forum for global economic and financial cooperation amongst the world's largest advanced and emerging economies, helps identifying global trends since the G20 represents 67% of the world's population, 85% of global GDP and over 75% of global trade. According to the FAOSTAT Online Database (2015), from 1961 to 2015, the population of the G20 member countries grew as follow: Argentina (101%), Australia (128%), Brazil (172%), Canada (96%), China (112%), France (40%), Germany (12%), India (180%), Indonesia (181%), Italy (23%), Japan (36%), Mexico (214%), South Korea (93%), Russian Federation (-5%), Saudi Arabia (611%), South Africa (200%), Turkey (172%), United Kingdom (21%), United States (72%), and the European Union (32%). Overall, from 1961 to 2015, the world's total population increased 138%, from 3.1 billion to 7.3 billion (FAOSTAT Online Database, 2015).

At the retail level, vegetables are sold in a variety of sizes, including by pound, quart, kilogram, basket, peck, carton, bushel, and paperboard box (Myers et al., 2014). In the Dallas/Fort Worth grocery market, fresh vegetables are predominately sold by count and by ounces. Unit sizes vary across vegetables (Table 2). Unit sizes by count range from 1 to 11, a count of 1 being the most common (Table 2). Unit sizes by ounce, on the other hand, usually range from 1 to 80 ounces, but sometimes there are unusual unit sizes of 160 ounces, 400 ounces, and 4475 ounces (Table 2). In 2012, in the Dallas/Fort Worth fresh vegetable market, lettuce had the largest volume share (65.72%) when considering fresh vegetables sold by count (Table 4, top section), followed by celery (13.59%), onions (8.30%), tomatoes (6.81%), and cauliflower (3.75%). When considering fresh vegetables sold by ounces (Table 4, bottom section), carrots had the largest volume share (34.49%), followed by precut salad mix (28.61%), onions (16.58%), tomatoes (14.86%), celery (2.37%), and spinach (2.24%). Overall, in terms of sales in dollars (sales by count plus sales by ounces), precut salad mix has the largest market share

(35.85%), followed by lettuce (19.06%), carrots (13.35%), tomatoes (12.98%), celery (5.91%), onions (5.83%), spinach (4.77%), cauliflower (1.81%), and radishes (0.43%).

Growing populations, improved distribution systems, decreasing poverty levels and more health conscious consumers play a key role in the rising demand for vegetables. As world vegetable consumption increases, it becomes exceedingly important for vegetable producers to become aware and understand global and local markets. This study provides a brief overview of some global vegetable trends and an in-depth analysis of the fresh vegetable market in the Dallas Fort Worth Metropolitan Area. The study may yield invaluable information to producers and investors who sell to grocery chains, farmers' markets and food service providers. A better understanding of emerging consumption trends as well as the substitution patterns among different fresh vegetables will be beneficial to producers. The general objective of this study is to provide an in-depth analysis of the fresh vegetable market in the Dallas Fort Worth Metropolitan Area using a theoretically sound research approach that estimates fresh vegetable demand elasticities. The specific objective of this study is to analyze trends as well as discuss the factors affecting the world vegetable demand and the fresh vegetable market in the Dallas Fort Worth metropolitan area.

Methods and Procedures

Various demand systems have been used to analyze demand for fresh fruits and vegetables, including the Rotterdam model (e.g., Seale et al., 2013), the AIDS (e.g., Thompson, 2003), the linear approximation of the AIDS (e.g., Padilla and Acharya, 2009; Naanwaab and Yeboah, 2012), the quadratic AIDS (e.g., Thompson, 2003), first difference version of the AIDS (e.g., Jung et al., 2005), and the inverse AIDS (e.g., Grant and Foster, 2005). Henneberry et al. (1999) used a misspecification test to show that the Rotterdam functional form was not an appropriate representation of the fruit and vegetable demand system that they considered. This study will use Deaton and Mullbauer's (1980) Almost Ideal Demand System (AIDS) to estimate how fresh tomatoes perform at the retail level.

Deaton and Muelbauer's (1980) AIDS model is considered an arbitrary first order approximation of any demand system. It satisfies the axioms of choice and aggregates perfectly over consumers up to a market demand function without invoking parallel linear Engel curves. The functional form is consistent with household-budget data, can be used to test the properties of homogeneity and symmetry through linear restrictions on fixed parameters, and is not difficult to estimate. In the AIDS model, the Marshallian demand function for commodity *i* in share form is specified as:

$$(1) \qquad w_{it} = \alpha_i + \sum_j \gamma_{ij} \log(p_{jt}) + \beta_i \log[X_t/P_t] + \varepsilon_{it},$$

where w_{it} is the budget share for commodity i at time t; p_{jt} is the price of commodity j at time t; X_t is total household expenditure on the commodities being analyzed; α_i, β_i and γ_{ij} are parameters, ε_i is a random term of disturbances, and P_t is a price index.

In a nonlinear approximation, the price index P_t is defined as:

$$(2) \qquad \log (P_t) = \alpha_0 + \sum_k \alpha_k \log (p_{kh}) + \frac{1}{2} \sum_k \sum_j \gamma_{kj} \log(p_{kh}) \log(p_{jh}).$$

The demand theory properties of adding-up, homogeneity and symmetry are imposed on the system of equations by restricting parameters in the model as follows:

$$(3) \qquad \text{Adding-up:} \qquad \sum_i \alpha_i = 1, \sum_j \gamma_{ij} = 0, \text{ and } \sum_i \beta_i = 0;$$

$$(4) \qquad \text{Homogeneity:} \qquad \sum_i \gamma_{ij} = 0;$$

$$(5) \qquad \text{Symmetry:} \qquad \gamma_{ij} = \gamma_{ji}.$$

The parameter estimates and the mean expenditure shares are used to estimate the Marshallian (uncompensated) and the Hicksian (compensated) price elasticities as well as the expenditure elasticities. Following Green and Alston (1990), the elasticities are estimated as:

(6) Marshallian Price Elasticity: $e_{ij} = \frac{\gamma_{ij}}{w_i} - \frac{\beta_i}{w_i}\left(\alpha_i + \sum_k \gamma_{kj} \log(p_k)\right) - \delta_{ij}$

(7) Hicksian Price Elasticity: $e_{ij}^c = e_{ij} + w_j e_i$

(8) Expenditure Elasticity: $e_i = 1 + \frac{\beta_i}{w_i}$

where δ_{ij} is the Kronecker delta, which is equal to 1 if $i = j$ and equal to 0 if otherwise.

The equation holding the smallest budget share equation is usually omitted from the demand system estimation. However, after the estimation of the demand system, the parameters of the omitted equation are recovered using equations (3) through (5).

Data and Procedures

Supermarket grocery data for the Dallas/Fort Worth market was obtained from The Nielsen Company for the year 2012. This consumers' scanner data is reported in four-week cycles from January 1 through December 29, 2012, and it includes sales (dollars and units), unit sizes, size description, and average unit prices. Fresh vegetable product items grouped by universal product codes are ranked by sales ($) in an item rank report. Each unit is reported sold by count (ct.) or by ounce (oz.). Table 3 summarizes the total number of non-zero observations that were included in each fresh vegetable item rank report. Table 4 reports the total quantities sold and average prices for each of the vegetable categories reported in the period January 1 through December 29, 2012. As it can be calculated from Table 4, the precut salad mix generated the highest revenue ($33.3 million), followed by lettuce ($17.7 million), carrots ($12.4 million), tomatoes ($12.1 million), celery ($5.5 million), onions ($5.4 million), spinach ($4.4 million), cauliflower ($1.7 million), and radishes ($0.4 million).

Results

The full AIDS model was estimated for the fresh vegetables product items sold by count (ct.) and the items sold by ounce (oz.) using an iterated seemingly unrelated regression (ITSUR) procedure in SAS version 9.3. The theoretical neoclassical restrictions, equations (3) through (5), were incorporated in estimation of the model, equations (1) and (3). The fresh vegetables included in the estimation of the model for the product items sold by count (ct.) include cauliflower, celery, lettuce, onions, and tomatoes. The fresh vegetables included in the estimation of the model for the product items sold by ounce (oz.) include carrots, tomatoes, salad, and onions. The corresponding budget shares are depicted in Figure 1 and Figure 2. As summarized in Table 4, some fresh vegetables had very small volume and budget shares and had to be excluded from the estimation of the demand system. The omitted fresh vegetables were included in preliminary estimation of the model; but when included, the parameter estimates failed to converge after 5000 iterations. Once they were excluded, the full AIDS model provided a better fit of the data.

Table 5 reports the AIDS model parameter estimates from the fresh vegetable items sold by count (ct.). Of the twenty four parameter estimated (α_i, $i = 1, \ldots, 5$; γ_{1j}, $j = 1, \ldots, 5$; γ_{2j}, $j = 2, \ldots, 5$; γ_{3j}, $j = 3, 5$; γ_{4j}, $j = 4, 5$; γ_{5j}, $j = 5$; and β_i, $\mathrm{i} = 1, \ldots, 4$), six were significant at 5% probability level, two at the 10% probability level, two at the 20% probability level, and fourteen were not significant. In terms of goodness of fit, 73.52% of the total variation in the budget share for cauliflower is explained by the AIDS model. Similarly, 58.19%, 71.15%, and 97.41% of the total variation in the budget shares for celery, lettuce, and onions are explained by the AIDS model respectively.

Table 6 reports the AIDS model parameter estimates from the fresh vegetable items sold by count (oz.). Of the seventeen parameter estimated (α_i, i = 1, …, 4; γ_{1j}, j = 1, …, 4; γ_{2j}, j = 2, …, 4; γ_{3j}, j = 3, 4; γ_{4j}, j = 4; and β_i, i = 1, …, 3), eight were significant at the 5% probability level, three at the 10% probability level, and nine were not significant. In terms of goodness of fit, 91.11% of the total variation in the budget share for carrots is explained by the AIDS model. Similarly, 64.84% and 55.50% of the total variation in the budget shares for tomatoes and precut salad mix are explained by the AIDS model respectively.

Tables 7, 8, 9 and 10 report the Marshallian (uncompensated) and Hicksian (compensated) price elasticities. All own-price elasticities have the expected negative sign. For example, a 1% increase in the tomato price ($/ct.) decreases the consumption of tomatoes (ct.) by 1.6714% (Table 9). However, if the tomato is sold in ounces, a 1% increase in the tomato price ($/oz.) decreases the consumption of tomatoes (oz.) by 1.0758% (Table 10). Among the fresh vegetables sold by ounce (Table 10), onions have the most inelastic elasticity ($\hat{e}_{44}^{c} = -0.4815$) while carrots have the most elastic elasticity ($\hat{e}_{11}^{c} = -2.8073$). Among the fresh vegetables sold by count (Table 9), lettuce has the most inelastic elasticity ($\hat{e}_{33}^{c} = -0.2692$) while celery has the most elastic elasticity ($\hat{e}_{22}^{c} = -2.1226$). In addition, the Hicksian own-price elasticity for tomatoes when sold by count equals -1.6714 (Table 9) while when sold by ounce it equals -1.0758 (Table 10). Similarly, the Hicksian own-price elasticity for onions when sold by count equals -0.9128 (Table 9) while it equals -0.4815 when sold by ounce. This seems to suggest own-price elasticities are more inelastic when the fresh vegetable is sold by ounce. Perhaps this is because it is harder for the consumer to recall or keep track of retail prices in $/oz. or $/lb. than it is to recall or keep track of retail prices in $/ct. That is, since it is easier to recall the price of one tomato or one onion, the consumer may be more responsive when the per-unit price changes.

Can you tell how many tomatoes weight one pound? When was the last time you used the supermarket balance to calculate how much you tomatoes will cost you?

Excluding own-price elasticities, there are generally as many negative cross-price elasticities as there are positive cross-price elasticities (8 positive Marshallian cross-price elasticities, 12 negative cross-price elasticities, 10 positive Hicksian cross-price elasticities, and 10 Hicksian cross-price elasticities) in the case of fresh vegetables sold by count (Tables 7 and 9). In the case of fresh vegetables sold by ounce (Tables 8 and 10), excluding own-price elasticities, there were twice as many positive cross-price elasticities than negatives (8 positives and 4 negatives). Positive cross-price elasticities suggest supplementary fresh vegetables while negatives suggest complementary fresh vegetables. For example, when the fresh vegetables are sold by count; lettuce and tomatoes, cauliflower and celery, and celery and onions are (gross and net) complements (and vice versa) while cauliflower and onions, celery and lettuce, and tomatoes and cauliflower are (gross and net) substitutes (and vice versa). The signs of the Marshallian price elasticities (Tables 7 and 8) are the same as their corresponding Hicksian price elasticities (Tables 9 and 10), except for the lettuce-onions cross-price elasticity ($\hat{e}_{34} < 0$ while $\hat{e}_{34}^{c} > 0$) and the onion-lettuce cross-price elasticity ($\hat{e}_{43} < 0$ while $\hat{e}_{43}^{c} > 0$) in the case of fresh vegetables sold by count (Tables 7 and 9).

Elasticity estimates among the fresh vegetables reported are currently not available for the Dallas/Fort Worth fresh vegetables market. Consequently, only indirect comparisons with previous aggregated U.S. elasticity estimates are possible. When comparing elasticities, it’s important to remember that differences in model functional forms, sample sizes, and time period under consideration, among other things, influence elasticity estimates to differ from one another.

Tables 11 and 12 report the expenditure elasticities. All but one expenditure elasticity estimate in each model has the expected positive sign. Celery, lettuce, onions, and tomatoes are "normal" goods while cauliflower and carrots are "inferior" goods. A 1% increase in the consumers' budget for celery increases the consumption of celery by 0.9402%. Likewise for lettuce, onions, tomatoes. On the contrary, a 1% increase in the consumers' budget for cauliflower decreases the consumption of cauliflower by 0.3255%. Similarly, a 1% increase in the consumers' budget for carrots decreases the consumption of carrots by 0.3934%.

In addition, notice that most expenditure elasticities are greater than one, which suggest the fresh vegetable is considered a "luxury"; in the sense that consumers are very responsive to changes in their budget. That is, slight changes in the consumers' budget for fresh vegetables will result in consumers adjusting their consumption significantly. For example, 1% increase in the consumers' budget for fresh vegetables is expected to increase lettuce and tomato consumption by 1.1159% and 1.1285% respectively (Table 11). On the contrary, if the expenditure elasticity is close to zero; then, the good is considered more of a "necessity" than "luxury". That is, if the expenditure elasticity is close to zero, the consumers are irresponsive to changes in their budget for fresh vegetables.

Conclusion

World vegetable production has increased considerably over the last five decades. The United States is the third largest vegetable producing country in the world. It also ranks third as the largest vegetable consuming country in aggregated terms and seventh in per-capita terms. Population growth plays a key role in the increasing demand for food. From 1961 to 2013, while the world's total population increased 138%, the world vegetable production increased 483% .

For the same period, while the United States population increased 72%, the United States production of vegetables increased 138%.

In the world market, tomatoes have the largest volume share (62%) followed by carrots (13%), lettuce (10%), cauliflower (8%), spinach (6%), and onions (2%). In the Dallas/Fort Worth grocery market, fresh vegetables are predominately sold by count and by ounces. When considering fresh vegetables sold by count in 2012, lettuce had the largest volume share (65.72%), followed by celery (13.59%), onions (8.30%), tomatoes (6.81%), and cauliflower (3.75%). When considering fresh vegetables sold by ounces in 2012, carrots had the largest volume share (34.49%), followed by precut salad mix (28.61%), onions (16.58%), tomatoes (14.86%), celery (2.37%), and spinach (2.24%).

As world vegetable consumption increases, it becomes exceedingly important for vegetable producers to become aware and understand global and local markets. This study provides a brief overview of some global vegetable trends and an in-depth analysis of the fresh vegetable market in the Dallas Fort Worth Metropolitan Area. The study may yield invaluable information for producers and investors who anticipate sells to grocery chains, farmers' markets and food service providers. A better understanding of emerging consumption trends as well as the substitution patterns among different fresh vegetables will be beneficial to producers.

Unlike previous fresh fruit and vegetable studies (Brandow, 1961; George and King, 1971; Brumfield et al., 1993; You et al., 1996; Henneberry et al., 1999; Agarwal and Rao, 2000; Thompson, 2003; Grant and Foster, 2005; Jung et al. 2005; Nzaku and Houston, 2009; Padilla and Acharya, 2009; Deghan et al., 2011; Naanwaab and Yeboah, 2012; Niu and Wohlegenaut, 2012; Seale et al., 2013), this study reports disaggregated fresh vegetable elasticity estimates which were not previously available. The analysis identifies fresh vegetables that are highly marketable in the Dallas/Fort Worth metropolitan area and may provide insight to local vegetable growers on how to market their produce.

Marshallian and Hicksian price elasticities and expenditure elasticities were estimated for fresh vegetable items sold by ounce (oz.) and by count (ct.). All own-price elasticities have the expected negative sign. Among the fresh vegetables sold by ounce, onions have the most inelastic elasticity while carrots have the most elastic elasticity. Among the fresh vegetables sold by count, lettuce has the most inelastic elasticity while celery has the most elastic elasticity. The Hicksian own-price elasticities for tomatoes and onions were consistently higher when sold by count than when sold by ounce. This seems to suggest own-price elasticities are more inelastic when the fresh vegetable is sold by ounce.

Generally, there were as many negative cross-price elasticities as there are positive cross-price elasticities (8 positive Marshallian cross-price elasticities, 12 negative cross-price elasticities, 10 positive Hicksian cross-price elasticities, and 10 Hicksian cross-price elasticities) in the case of fresh vegetables sold by count. In the case of fresh vegetables sold by ounce, excluding own-price elasticities, there were twice as many positive cross-price elasticities than negatives (8 positives and 4 negatives). When the fresh vegetables are sold by count; lettuce and tomatoes, cauliflower and celery, and celery and onions were found to be (gross and net) complements (and vice versa) while cauliflower and onions, celery and lettuce, and tomatoes and cauliflower were found to be (gross and net) substitutes (and vice versa). The signs of the Marshallian price elasticities were the same as their corresponding Hicksian price elasticities, except for the lettuce-onions cross-price elasticity and the onion-lettuce cross-price elasticity.

All but one expenditure elasticity estimate in each model had the expected positive sign. Celery, lettuce, onions, and tomatoes were found to be “normal” goods while cauliflower and carrots were found to be "inferior" goods. In addition, most expenditure elasticities were greater than one, which suggest consumers are sensitive to changes in their budget.

Finally, this study used a demand system approach to estimate price and expenditure elasticities for several fresh vegetables using AC Nielsen Homescan consumption data from the Dallas/Fort Worth grocery market in 2012. Due to financial constraints, only one year of data from AC Nielsen Homescan data was purchased. The study could be easily expanded to include more years, provided additional funds were available. The study could also use the estimated elasticities to generate a sensitivity analysis of likely fresh vegetable prices for vegetable growers in the Dallas/Fort Worth area and combine it with data from local production practices to conduct a profitability analysis.

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Tables

Table 1. Ten Largest World's Vegetable Producing Countries, 1961-2013 Average.

Carrots	Cauliflower	Lettuce	Onions	Spinach	Tomatoes	Vegetables
China (26.91%)	China (31.61%)	China (35.93%)	Japan (22.27%)	China (77.66%)	China (19.03%)	China (25.26%)
Russia (10.39%)	India (31.04%)	United States (24.48%)	South Korea (14.73%)	Japan (4.82%)	United States (11.84%)	Spain (14.06%)
United States (7.82%)	Italy (5.10%)	Italy (6.51%)	China (12.58%)	United States (3.36%)	Turkey (7.09%)	United States (10.91%)
Poland (4.17%)	France (4.28%)	Spain (5.42%)	Nigeria (6.00%)	Turkey (2.20%)	Italy (6.37%)	Egypt (10.73%)
United Kingdom (3.98%)	Spain (3.11%)	India (4.78%)	Turkey (5.78%)	Indonesia (1.47%)	India (5.99%)	Italy (7.69%)
Japan (3.74%)	United Kingdom (2.81%)	France (3.48%)	New Zealand (5.02%)	France (1.42%)	Egypt (5.54%)	India (7.64%)
Ukraine (3.52%)	United States (2.44%)	Japan (3.02%)	Iraq (4.62%)	Italy (1.39%)	Russia (5.34%)	Turkey (5.04%)
Uzbekistan (3.46%)	Poland (1.92%)	Turkey (1.45%)	Tunisia (3.85%)	Belgium (1.20%)	Spain (3.54%)	Russia (4.70%)
France (3.42%)	Germany (1.74%)	Belgium-Luxem. (1.43%)	Ecuador (2.97%)	South Korea (1.00%)	Brazil (2.73%)	Japan (2.13%)
Germany (2.46%)	Mexico (1.56%)	United Kingdom (1.36%)	North Korea (2.79%)	Pakistan (0.92%)	Iran (2.58%)	Mexico (1.84%)

Source: FAOSTAT Online Database, computed by authors.

Table 2. Sizes Reported in the Random Sample of Fresh Vegetable Sales from the Dallas/Fort Worth Grocery Market in 2012.

Carrots		Cauliflower		Celery		Lettuce		Onions		Radishes		Spinach		Tomatoes		Precut Salad Mix		
ct.	oz.	ct.	oz.	ct.	oz.	ct.	oz.	ct.	oz.	ct.	oz.	ct.	oz.	ct.	oz.	ct.	oz.	oz.
1	2	1	10†	1	7†	1		1	1†	1	6	1	5	1	6‡	1†	4†	10.5
7†	2.25‡		12‡		8†	2		2†	3	11†	16		6‡	4	8		4.5‡	10.6†
	2.75‡				12†	3		3†	4†				8.5†	6‡	9†		4.75†	10.75†
	3				14	4		4†	4.5†				9‡		10		5	10.8†
	6†				16				5				10		10.5		5.5	10.9†
	8				20†				5.5†				11‡		12		6	11
	10				24‡				6				16		14‡		6.4†	11.5†
	12								7				40†		16		6.5	11.55†
	14								8						19.2†		6.9†	12
	16								10						20‡		6.97†	12.55†
	32								14‡						22†		7	12.7†
	36†								16						32‡		7.75†	12.74†
	48								32						38.24†		8	12.9†
	80								48						64†		8.3†	13†
	400‡								64						4475†		8.5	13.9†
									80								8.75‡	14‡
									160†								8.9†	14.5†
																	8.99†	14.9†
																	9	15†
																	9.4†	16
																	9.7†	18
																	9.9‡	24
																	10	32‡
																	10.25†	48‡

Note: Sizes that correspond to only one and two universal product codes are denoted by daggers (†) and double daggers (‡) respectively.

Table 3. Number of Non-zero Observations in Each Fresh-Vegetable Dataset.

Fresh-Market Vegetable	Items reported sold by count (ct.)	Items reported sold by ounce (oz.)	Total Number of Observations
Carrots	4	93	97
Cauliflower	20	3	23
Celery	20	20	40
Lettuce	86	0	86
Onions	10	123	133
Radishes	4	6	10
Spinach	3	25	28
Tomatoes	31	83	114
Precut Salad Mix	1	236	237

Table 4. Random Sample of Fresh Vegetable Sales from the Dallas/Fort Worth Grocery Market in 2012.

	Carrots	Cauliflower	Celery	Lettuce	Onions	Radishes	Spinach	Tomatoes	Salad
Quantity (ct.)	33,056	766,911	2,781,265	13,448,964	1,699,413	7,925	331,086	1,394,201	98
Price ($/ct.)	1.3945	2.1413	1.3999	1.3173	0.7183	0.1664	1.3605	0.6528	14.8308
Volume Share	0.16%	3.75%	13.59%	65.72%	8.30%	0.04%	1.62%	6.81%	0.0005%
Budget Share	0.18%	6.34%	15.04%	68.45%	4.72%	0.01%	1.74%	3.52%	0.0056%
Quantity (lbs.)	9,776,866	7,851	671,529	0	4,700,386	232,904	636,338	4,212,733	8,112,120
Price ($/lb.)	1.2644	4.6614	2.3808	n.a.	0.8925	1.7281	6.2627	2.6477	4.1072
Volume Share	34.49%	0.03%	2.37%	0.00%	16.58%	0.82%	2.24%	14.86%	28.61%
Budget Share	18.44%	0.05%	2.38%	0.00%	6.26%	0.60%	5.94%	16.64%	49.69%

Note: Table 3 report sample sizes for fresh vegetables sold by count (ct.) and by ounce (oz.). Vegetables sold by ounce (oz.) were converted into vegetables sold by pound (lb.).

Table 5. AIDS Model Parameter Estimates from Fresh Vegetable Items Sold by Count (ct.).

	Cauliflower		**Celery**		**Lettuce**		**Onions**		**Tomatoes**	
Coeff.	Coeff.	Std Err	Coeff.	Std Err	Coeff.	Std Err	Coeff.	Std Err	Coeff.	Std Err
α_i	1.3666*	0.5194	0.3158	1.1839	-0.4308	1.1814	-0.1272	0.2024	-0.1243	0.3397
γ_{i1}	-0.0735	0.0841	-0.0411	0.0964	-0.0684	0.1205	0.0724*	0.0199	0.1107*	0.0275
γ_{i2}	-0.0411	0.0964	-0.1971*	0.0683	0.2354‡	0.1214	-0.0186	0.0138	0.0215	0.0164
γ_{i3}	-0.0684	0.1205	0.2354‡	0.1214	-0.0635	0.1976	-0.0360†	0.0228	-0.0674‡	0.0316
γ_{i4}	0.0724*	0.0199	-0.0186	0.0138	-0.0360†	0.0228	0.0006	0.0097	-0.0183†	0.0109
γ_{i5}	0.1107*	0.0275	0.0215	0.0164	-0.0674‡	0.0316	-0.0183†	0.0109	1.8626*	0.7194
β_i	-0.0860*	0.0367	-0.0092	0.0846	0.0809	0.0843	0.0098	0.0144	0.0046	n.a.
Goodness of Fit										
	R^2	$\overline{R^2}$	R^2	$\overline{R^2}$	R^2	$\overline{R^2}$	R^2	$\overline{R^2}$	R^2	$\overline{R^2}$
	0.7352	0.6148	0.5819	0.3919	0.7115	0.5804	0.6741	0.5260	n.a.	n.a.

Note: Significant at the 0.05, 0.10, and 0.20 probability levels are indicated by asterisks (*), double daggers (‡), and daggers (†) respectively, except for the parameter coefficient estimates whose standard errors are not available (n.a.) because they correspond to the omitted equation in the system.

Table 6. AIDS Model Parameter Estimates from Fresh Vegetable Items Sold by Ounce (oz.).

	Carrots		**Tomatoes**		**Salad**		**Onions**	
Coeff.	Coeff.	Std Err	Coeff.	Std Err	Coeff.	Std Err	Coeff.	Std Err
α_i	4.0403	0.5437	2.3206*	0.3867	-5.1730*	0.8468	-0.1879	0.7767
γ_{i1}	-2.2369*	0.9177	-1.0410*	0.2807	3.0572‡	1.4164	0.2208	0.3250
γ_{i2}	-1.0410*	0.2807	-0.5464*	0.1242	1.4822*	0.4921	0.1052	0.1874
γ_{i3}	3.0572‡	1.4164	1.4822*	0.4921	-4.1970‡	2.2658	-0.3424	0.4642
γ_{i4}	0.2208	0.3250	0.1052	0.1874	-0.3424	0.4642	0.1518‡	0.0760
β_i	-0.2823*	0.0550	-0.1474	0.0182	0.4046*	0.0925	0.0251	n.a.
Goodness of Fit								
	R^2	$\overline{R^2}$	R^2	$\overline{R^2}$	R^2	$\overline{R^2}$	R^2	$\overline{R^2}$
	0.9111	0.8769	0.6484	1.2824	0.5550	0.3839	n.a.	n.a.

Note: Significant at the 0.05, 0.10, and 0.20 probability levels are indicated by asterisks (*), double daggers (‡), and daggers (†) respectively, except for the parameter coefficient estimates whose standard errors are not available (n.a.) because they correspond to the omitted equation in the system.

Table 7. Marshallian Price Elasticities for Fresh Vegetable Items Sold by Count (ct.).

i\j	Cauliflower	Celery	Lettuce	Onions	Tomatoes
Cauliflower	-0.5323	-0.2683	-1.5522	1.0068	1.6715
Celery	-0.1955	-2.2670	1.5102	-0.1262	0.1383
Lettuce	-0.2380	0.3056	-1.0475	-0.0422	-0.2666
Onions	1.2583	-0.4427	-0.6722	-0.9707	-0.6772
Tomatoes	1.5500	0.2953	-0.9902	-0.2716	-1.7120

Table 8. Marshallian Price Elasticities for Fresh Vegetable Items Sold by Ounce (oz.).

i\j	Carrots	Tomatoes	Salad	Onions
Carrots	-2.7276	-0.1668	2.9056	0.3822
Tomatoes	-0.3037	-1.1112	1.0556	0.1657
Salad	0.6459	0.0706	-2.2069	-0.2508
Onions	0.7698	0.2263	-1.7860	-0.5754

Table 9. Hicksian Price Elasticities for Fresh Vegetable Items Sold by Count (ct.).

i\j	Cauliflower	Celery	Lettuce	Onions	Tomatoes
Cauliflower	-0.5535	-0.3183	-1.7792	0.9911	1.6598
Celery	-0.1345	-2.1226	2.1660	-0.0809	0.1720
Lettuce	-0.1656	0.4770	-0.2692	0.0115	-0.2265
Onions	1.3364	-0.2580	0.1665	-0.9128	-0.6340
Tomatoes	1.6232	0.4686	-0.2031	-0.2173	-1.6714

Table 10. Hicksian Price Elasticities for Fresh Vegetable Items Sold by Ounce (oz.).

i\j	Carrots	Tomatoes	Salad	Onions
Carrots	-2.8073	-0.2387	2.6909	0.3552
Tomatoes	-0.2645	-1.0758	1.1613	0.1790
Salad	0.9986	0.3889	-1.2564	-0.1311
Onions	1.0464	0.4759	-1.0408	-0.4815

Table 11. Expenditure Elasticities from Fresh Vegetable Items Sold by Count (ct.).

i	Expenditure Elasticities (η_i)
Cauliflower	-0.3255
Celery	0.9402
Lettuce	1.1159
Onions	1.2026
Tomatoes	1.1285

Table 12. Expenditure Elasticities from Fresh Vegetable Items Sold by Ounce (oz.).

i	Expenditure Elasticities (η_i)
Carrots	-0.3934
Tomatoes	0.1936
Salad	1.7411
Onions	1.3652

Figures

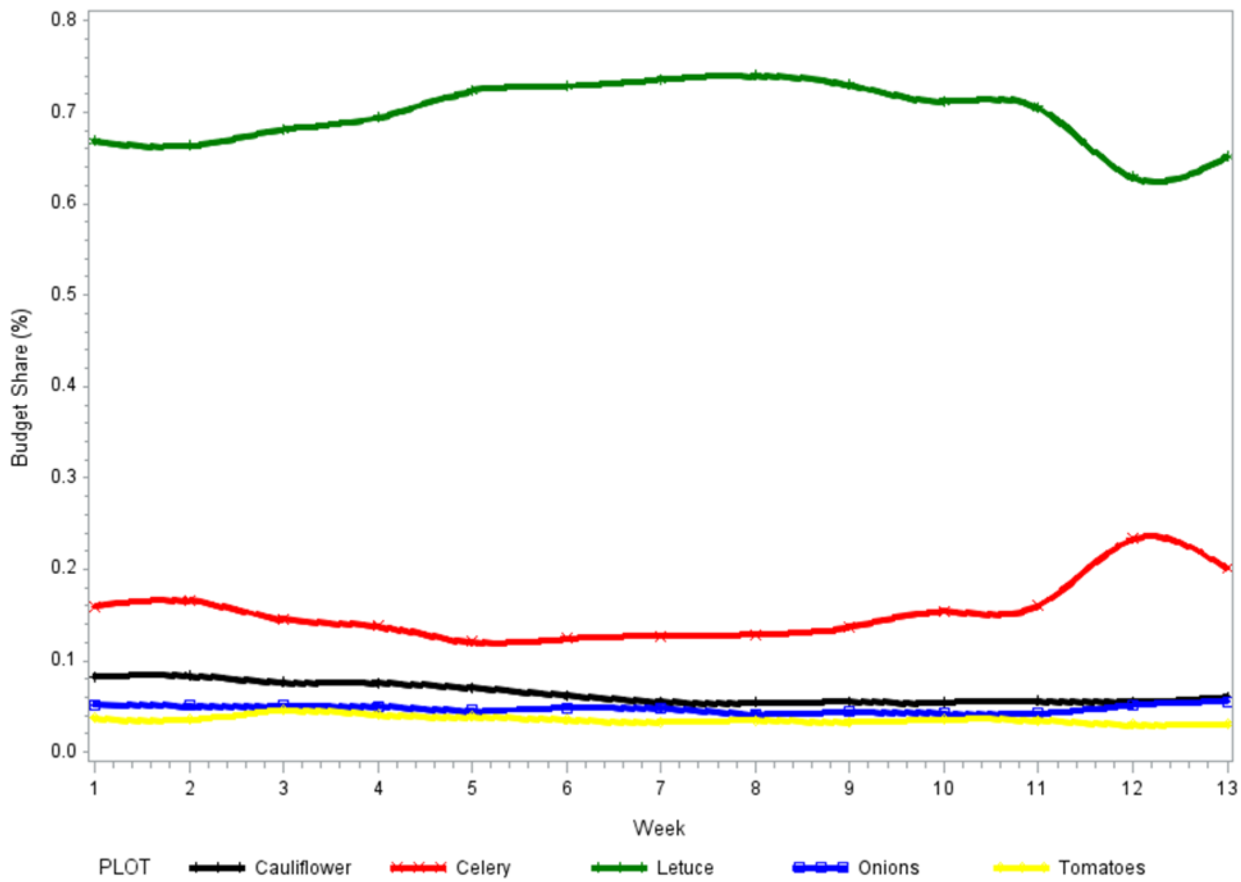

Figure 1. Budget Shares from a Random Sample of Fresh Vegetable Items Sold by Count (ct.) in the Dallas/Fort Worth Grocery Market in 2012.

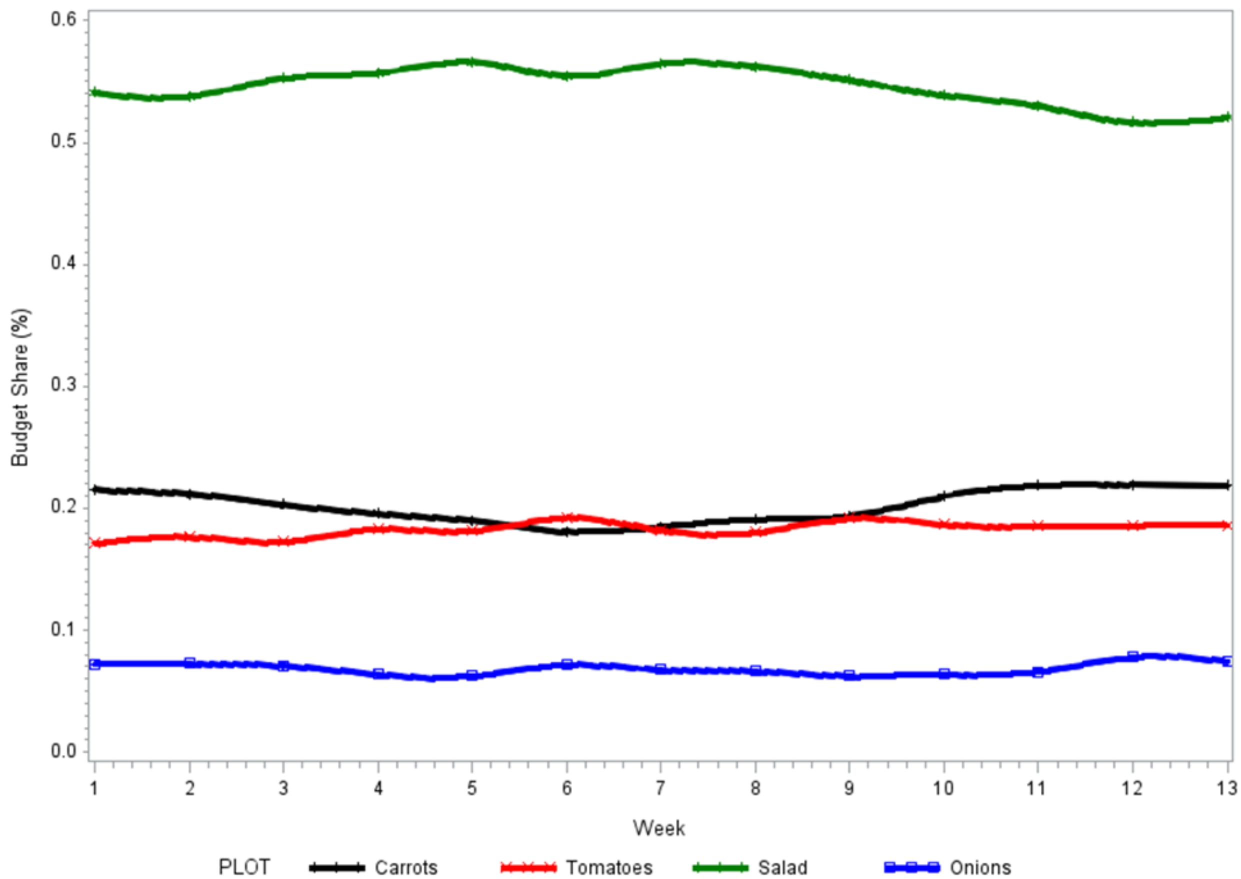

Figure 2. Budget Shares from a Random Sample of Fresh Vegetable Items Sold by Ounce (oz.) in the Dallas/Fort Worth Grocery Market in 2012.