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

Jose A. Lopez*

College of Agricultural Sciences and Natural Resources, Texas A&M University-Commerce, Commerce, TX 75429

ABSTRACT

This study estimates expenditure and price elasticities using home-scan fresh-vegetable consumption data from the Dallas-Fort Worth grocery market, the largest market in Northeast Texas. As vegetable consumption and production increases, it is critical for vegetable growers to keep up with production and consumption trends and recent substitution patterns. The study analyzed how various fresh vegetables perform at the retail level and found that consumers are not only responsive to changes in own-prices but also responsive to prices of other vegetables, and that own-price elasticity estimates seem to be more inelastic when fresh vegetables are sold by ounce than by count. The study may assist local producers identifying highly marketable fresh produce in the DFW metropolitan area and provide insight in assessing market profitability.

KEYWORDS: demand system; disaggregated analysis; elasticities; fresh vegetables

INTRODUCTION

World vegetable production increased 483.27% from 1961 to 2013 (Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT) 2015). Tomatoes represent the largest annual world production volume for the same period with an average share of 62% followed by carrots (13%), lettuce (10%), cauliflower (8%), spinach (6%), and onions (2%) (FAOSTAT 2015). From 1961 to 2013, the world's 10 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%) (FAOSTAT 2015). Together, these 10 countries account for 74.12% of the total world vegetable production. Table 1 summarizes the world's 10 largest producing countries for selected vegetables.

In terms of total vegetable consumption from 1961 to 2013, the world's 10 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%) (FAOSTAT 2015). These 10 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), and India (52.28 kg/year) (FAOSTAT 2015).

* Corresponding author: Jose.Lopez@tamuc.edu

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 (2015), computed by author.

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. From 1961 to 2015, the population of Argentina grew 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%) (FAOSTAT 2015). Overall, from 1961 to 2015, the world's total population increased 138%, from 3.1 billion to 7.3 billion (FAOSTAT 2015).

At the retail level in the United States, 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 (DFW) grocery market, fresh vegetables are predominately sold by count and by ounces at various unit sizes (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 ounce to 80 ounces, but sometimes there are unusual unit sizes of 160 ounces, 400 ounces, and 4475 ounces (Table 2). Sizes that correspond to only one and two universal product codes (UPC) are denoted by daggers (†) and double daggers (‡) respectively. All the other sizes correspond to at least more than two UPC. This gives the reader an idea of how many UPC showed up in the sample with that size. Since UPC are uniquely assigned to each item, the less UPC in a size, generally the less variety/competition within that size.

In 2012 in the DFW 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, middle 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 dollar terms (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%) (Table 4, bottom section).

The DFW metropolitan area consists of the counties of Denton, Tarrant, Johnson, Collin, Dallas, Ellis, Rockwall, and Koffman (Bennett and Hanselka 2013). Agriculture is a primary contributor to the metropolitan area which comprises over 910,000 acres of agricultural land (91% of the acres in crops and 9% in pasture) (Bennett and Hanselka 2013). From 2007 and 2012, the number of farms and land in farms in the DFW metropolitan region increase by 10%, while the number of farms and land in farms in the state of Texas only increased by about 0.55% and decreased 0.19%, respectively (Bennett and Hanselka 2013). The DFW metropolitan area enjoys of a healthy and increasing agriculture production base.

Notwithstanding, growing populations, improved distribution systems, decreasing poverty levels, and more health-conscious consumers play a key role in the increasing demand for vegetables. As vegetable consumption increases, it is important for vegetable producers to keep up with 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 DFW metropolitan area. The study provides valuable information to producers, who sell to grocery chains, farmers' markets, and food service providers, in understanding emerging consumption trends and the substitution patterns among fresh vegetables. The general objective of this study is to provide an in-depth analysis of the fresh vegetable market in the DFW metropolitan area using a theoretically-sound-research approach and to estimate fresh vegetable demand elasticities. 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. The specific objective of this study is to analyze trends and vegetable substitution patterns, and identify factors that affect fresh vegetable consumption.

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.

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). In addition, the literature reviewed suggested that the AIDS model provides a better representation of vegetable demand systems. For instance, Henneberry et al. (1999) concluded that the Rotterdam functional form was not an appropriate representation of their fruit and vegetable demand system. This study will use Deaton and Muellbauer's (1980) AIDS model to estimate how fresh vegetables 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:

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

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:

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

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:

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

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

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

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

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

Expenditure Elasticity: $$e_i = 1 + \frac{\beta_i}{w_i} \quad (7)$$

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 DFW market was obtained from The Nielsen Company for the year 2012. Households participating with The Nielsen Company use scanners to enter information about their households and their grocery purchases, including what, when, and where they buy the products. The consumers' scanner data used by this study was compiled and aggregated by The Nielsen Company into four-week cycles from January 1 through December 29, 2012, and it includes sales (in 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 sum of quantities sold and average prices for each of the vegetable categories reported in the period January 1 through December 29, 2012. In 2012, in the DFW grocery market, the precut salad mix generated the highest revenue (average revenue share of 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%).

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

Fresh-Market Vegetable	**Produce Reported Sold by Count (ct.)**	**Produce 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**
				Produce Sold by count (ct.)					
Quantity (ct.)	33,056	766,911	2,781,265	13,448,964	1,699,413	7,925	331,086	1,394,201	98
Price ($/ct.)	1.3945	2.1413	1.3999	1.3173	0.7183	0.1664	1.3605	0.6528	14.8308
Volume Share	0.16%	3.75%	13.59%	65.72%	8.30%	0.04%	1.62%	6.81%	0.00%
Budget Share	0.18%	6.34%	15.04%	68.45%	4.72%	0.01%	1.74%	3.52%	0.01%
				Produce Sold by ounce (oz.)					
Quantity (lbs.)	9,776,866	7,851	671,529	0	4,700,386	232,904	636,338	4,212,733	8,112,120
Price ($/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%
				Total ($)					
Sales	12,407,966	1,678,783	5,492,269	17,716,320	5,415,783	403,800	4,435,636	12,064,188	33,319,553
Budget Share	13.35%	1.81%	5.91%	19.06%	5.83%	0.43%	4.77%	12.98%	35.85%

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 pounds (lb.).

RESULTS

The AIDS model was estimated for the fresh vegetables sold by count (ct.) and 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 the estimation of the model, equations (1) and (3). To address the problem of random unit of measurements for produce sold by count (ct.), the study estimates two demand systems: one for fresh vegetable sold by count (ct.) and one for fresh vegetables sold by ounce (oz.). One of the major limitations of the study is that it addressed the unit of measurement "by count" by separating the demand for vegetables according to their sales unit (i.e., ct. or oz.). Since vegetables sold by count or by unit of weight are not likely to be described independently of the quantities of consumed by the other (i.e., the assumption of weak separability may not hold), it is preferred to keep them in the same group so that consumer preferences can be described in terms of both of them (i.e., dependently).[1]

The fresh vegetables included in the estimation of the model for produce sold by count (ct.) are cauliflower, celery, lettuce, onions, and tomatoes while the fresh vegetables included in the estimation of the model for produce sold by ounce (oz.) are carrots, tomatoes, salad, and onions. The corresponding budget shares are depicted in Figures 1 and 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 convergence criterion was met and the AIDS model provided a better fit of the data.

Table 5 reports the AIDS model parameter estimates from the fresh vegetables sold by count (ct.). Of the twenty-four parameters 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, $i = 1, \ldots, 4$), eight were significant at the 10% probability level while sixteen 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%, 67.41%, and 21.40% of the total variation in the budget shares for celery, lettuce, onions, and tomatoes are explained by the AIDS model respectively.

[1] The problem with vegetables sold "by count" is that the weight of the vegetable is unknown. The study separated the demand for vegetables according to their sales unit (i.e., ct. or oz.) to avoid complications of combining quantities in ct. with quantities in ounces and prices in \$/ct. with prices in \$/oz. (or \$/lb.).

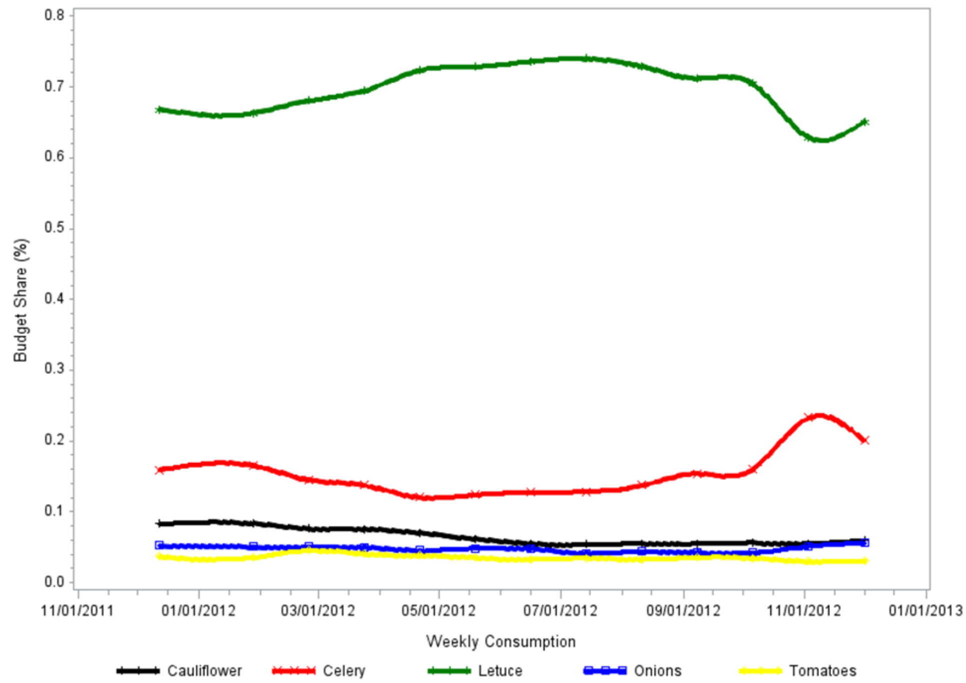

Figure 1. Budget Shares from a Random Sample of Fresh Vegetables Sold by Count (ct.) in the Dallas-Fort Worth Grocery Market in 2012.

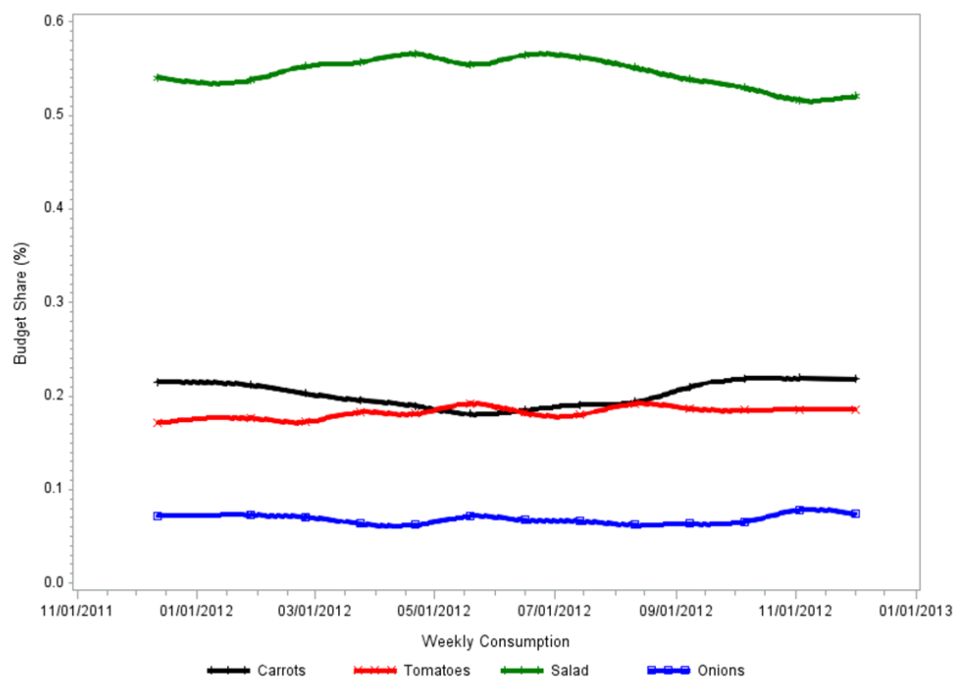

Figure 2. Budget Shares from a Random Sample of Fresh Vegetables Sold by Ounce (oz.) in the Dallas-Fort Worth Grocery Market in 2012.

Table 5. AIDS Model Parameter Estimates, Fresh Vegetables Sold by Count (ct.).

	Cauliflower		**Celery**		**Lettuce**		**Onions**		**Tomatoes**	
Par.	Par. Est.	Std. Err.	Par. Est.	Std. Err.	Par. Est.	Std. Err.	Par. Est.	Std. Err.	Par. Est.	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_{1i}	-0.0735	0.0841	-0.0411	0.0964	-0.0684	0.1205	0.0724*	0.0199	0.1107*	0.0275
γ_{2i}	-0.0411	0.0964	-0.1971*	0.0683	0.2354*	0.1214	-0.0186	0.0138	0.0215	0.0164
γ_{3i}	-0.0684	0.1205	0.2354*	0.1214	-0.0635	0.1976	-0.0360	0.0228	-0.0674*	0.0316
γ_{4i}	0.0724*	0.0199	-0.0186	0.0138	-0.0360	0.0228	0.0006	0.0097	-0.0183	0.0109
γ_{5i}	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.	0.0240
	Goodness of Fit and Serial Correlation									
	R^2	DW	R^2	DW	R^2	DW	R^2	DW		
	0.7352	1.7804	0.5819	0.5363	0.7115	0.9527	0.6741	2.0001		

Note: Significance at the 0.10 probability levels are indicated by asterisks (*).

Table 6. AIDS Model Parameter Estimates, Fresh Vegetables Sold by Ounce (oz.).

	Carrots		**Tomatoes**		**Salad**		**Onions**	
Par.	Par. Est.	Std. Err.	Par. Est.	Std. Err.	Par. Est.	Std. Err.	Par. Est.	Std. Err.
α_i	4.0403	0.5437	2.3206*	0.3867	-5.1730*	0.8468	-0.1879	0.7767
γ_{1i}	-2.2369*	0.9177	-1.0410*	0.2807	3.0572*	1.4164	0.2208	0.3250
γ_{2i}	-1.0410*	0.2807	-0.5464*	0.1242	1.4822*	0.4921	0.1052	0.1874
γ_{3i}	3.0572*	1.4164	1.4822*	0.4921	-4.1970*	2.2658	-0.3424	0.4642
γ_{4i}	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	0.0522
				Goodness of Fit and Serial Correlation				
	R^2	DW	R^2	DW	R^2	DW		
	0.9111	2.5873	0.6484	1.8536	0.5550	2.5672		

Note: Significance at the 0.10 probability levels are indicated by asterisks (*).

Table 6 reports the AIDS model parameter estimates from the fresh-vegetables 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), eleven were significant at the 10% probability level while six 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%, 55.50%, and 18.47% of the total variation in the budget shares for tomatoes, precut salad mix, and onions are explained by the AIDS model respectively.

Tables 7 and 8 report the Marshallian (uncompensated) price elasticities. All own-price elasticities have the expected negative sign. For example, a 1% increase in the tomato price ($/ct.) decreases the consumption of tomatoes (ct.) by 2.2893% (Table 7). However, if the tomato is sold in ounces, a 1% increase in the tomato price ($/oz.) decreases the consumption of tomatoes (oz.) by 1.1112% (Table 8). Among the fresh vegetables sold by ounce (Table 8), onions have the most inelastic elasticity of demand ($\hat{e}_{44} = -0.5754$) while carrots have the most elastic ($\hat{e}_{11} = -2.7276$). Among the fresh vegetables sold by count (Table 7), cauliflower has the most inelastic elasticity of demand ($\hat{e}_{11} = -0.5323$) while tomatoes have the most elastic ($\hat{e}_{55} = -2.2893$). In addition, the own-price elasticity for tomatoes when sold by count ($\hat{e}_{55}$) equals -2.2893 (Table 7) while when sold by ounce ($\hat{e}_{22}$) it equals -1.1112 (Table 8). Similarly, the own-price elasticity of demand for onions when sold by count ($\hat{e}_{44}$) equals -0.9707 (Table 7) while it equals -0.5754 when sold by ounce (Table 8). This seems to suggest own-price elasticities of demand are more inelastic when fresh vegetables are 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 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.[2] This suggests that retailers may be able to keep fresh-vegetable market shares relatively more stable by selling by ounce than by count

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

when vegetable prices are volatile. This also suggests that if the objective of the retailers were to increase profit from vegetables, which is not always the case, they could focus on raising prices on the vegetable sold by count instead of vegetables sold by weight.

Excluding own-price elasticities, in general, this study found about as many negative cross-price elasticities as there are positives (8 positive Marshallian cross-price elasticities, 12 negative Marshallian cross-price elasticities) in the case of fresh vegetables sold by count (Table 7). In the case of fresh vegetables sold by ounce (Table 8), 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 substitute fresh vegetables while negatives suggest complement fresh vegetables. For example, when the fresh vegetables are sold by count; lettuce and tomatoes, lettuce and cauliflower, cauliflower and celery, and celery and onions are (gross) complements (and vice versa) while cauliflower and onions, celery and lettuce, and tomatoes and cauliflower are (gross) substitutes (and vice versa). Our results are different from Naanwaab and Yeboah (2012) in that they obtained 52 negative cross-price elasticity estimates out of 56, with about 28 negatives and significant, indicating a high complementarity pattern among the fresh vegetables analyzed.

Table 7. Marshallian Price Elasticities, Fresh Vegetables 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	2.9262*	0.5623*	-1.8284	-0.4993*	-2.2893*

Note: Significance at the 0.10 probability levels are indicated by asterisks (*). Elasticities estimated at $\bar{w}_1$ = 0.0649, $\bar{w}_2$ = 0.1536, $\bar{w}_3$ = 0.6974, $\bar{w}_4$ = 0.0481, $\bar{w}_5$ = 0.0359, and corresponding prices reported in Table 4.

Table 8. Marshallian Price Elasticities, Fresh Vegetables 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

Note: Significance at the 0.10 probability levels are indicated by asterisks (*). Elasticities estimated at $\bar{w}_1$ = 0.2026, $\bar{w}_2$ = 0.1828, $\bar{w}_3$ = 0.5459, $\bar{w}_4$ = 0.0688, and corresponding prices in Table 4.

Unlike previous studies, this study reports elasticity estimates for the DFW fresh-vegetables market, which are currently not available. Therefore, our estimates can only be compared with previous U.S. elasticity estimates at the national level. When comparing elasticities, differences in model functional forms, sample sizes, and time period under consideration, among other things, influence elasticity estimates to differ from one another.

Previous estimates of the Marshallian own-price elasticity of demand for carrots range from -1.6530 in Henneberry et al. (1999) to -0.2420 in Naanwaab and Yeboah (2012) (Table 11); while in this study the DFW estimate is -2.7276 (Table 8). Similarly, the

Marshallian own-price elasticities of demand for celery and lettuce in previous studies range from -0.1000 in Naanwaab and Yeboah (2012) to -0.0501 in You et al. (1996) (Table 11) and from -0.3660 to -0.0470 in Naanwaab and Yeboah (2012), respectively;[3] while in this study the DFW estimates are -2.2670 for fresh celery and -1.0475 for fresh lettuce (Table 7). The author is unaware of recent elasticity estimates for fresh cauliflower and precut salad mix. In the case of fresh onions, the Marshallian own-price elasticity of demand for onion ranges from -0.2890 in Henneberry et al. (1999) to -0.1832 in You et al. (1996) (Table 11); while this study DFW estimates range from -0.9707 (Table 7) to -0.5754 (Table 8). Last, the Marshallian own-price elasticity for fresh tomatoes ranges from -1.1967 in Jung et al. (2005) to -0.2300 in Henneberry et al. (1999) (Table 11), while this study DFW estimates ranges from -2.2893 (Table 7) to -1.1112 (Table 8). Compared to previous studies, our elasticity estimates are slightly more elastic; which could be, among other things, because our demand system includes more vegetables than previous studies, and because our estimates are for the DFW grocery market rather than averaged over all consumers in the United States.

Tables 9 and 10 report the expenditure elasticities. All but one expenditure elasticity estimate in each demand system obtained the expected positive sign. Celery, lettuce, onions, and tomatoes were all found to be “normal” goods; while cauliflower and carrots were found to be “inferior” goods, but the latter two estimates were not statistically different from zero at the 10% significance level.[4] In addition, our expenditure elasticity estimates indicate that a 1% increase in the consumers’ budget for fresh vegetables increases the consumption of celery by 0.9402% (Table 9), everything else held constant. Similarly, a 1% increase in the consumers’ fresh vegetable budget increases the consumption of lettuce, onions, and tomatoes by 1.1159%, 1.2026% if sold by ounce or 1.3652% if sold by count, and 1.1285% if sold by ounce or 0.1936% if sold by count, respectively (Tables 9 and 10).

Table 9. Expenditure Elasticities, Fresh Vegetables Sold by Count (ct.).

i	Expenditure Elasticities ($\hat{e}_i$)
Cauliflower	-0.3255
Celery	0.9402
Lettuce	1.1159*
Onions	1.2026*
Tomatoes	1.1285

Note: Significance at the 0.10 probability levels are indicated by asterisks (*). Elasticities estimated at Elasticities estimated at $\overline{w}_1$ = 0.0649, $\overline{w}_2$ = 0.1536, $\overline{w}_3$ = 0.6974, $\overline{w}_4$ = 0.0481, $\overline{w}_5$ = 0.0359.

[3] Excluding the unusual significant own-price elasticity estimate of carrots of 0.2210 and the insignificant own-price elasticity estimate of lettuce of 0.0032 reported in Naanwaab and Yeboah (2012) (Table 11).

[4] The p-values of the expenditure elasticity estimates of cauliflower and carrots are 58.05% and 18.56%, respectively.

Table 10. Expenditure Elasticities, Fresh Vegetables Sold by Ounce (oz.).

i	Expenditure Elasticities ($\hat{e}_i$)
Carrots	-0.3934
Tomatoes	0.1936*
Salad	1.7411*
Onions	1.3652

Note: Significance at the 0.10 probability levels are indicated by asterisks (*). Elasticities estimated at $\bar{w}_1$ = 0.2026, $\bar{w}_2$ = 0.1828, $\bar{w}_3$ = 0.5459, and $\bar{w}_4$ = 0.0688.

Most of our expenditure elasticity estimates were greater than one, which suggest the fresh vegetables are more of a "luxury", in the sense that consumers are very responsive to changes in their expenditure budgets, than a "necessity". That is, slight changes in the consumers' expenditure budget for fresh vegetables will result in consumers adjusting their consumption considerably. For example, 1% increase in the consumers' budget for fresh vegetables is expected to increase lettuce and tomato (sold-by-count) consumption by 1.1159% and 1.1285% respectively (Table 9). 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, which seems to be the case of tomatoes sold by ounce (Table 10).

In previous studies, expenditure elasticity estimates for carrots, celery, lettuce, onions, and tomatoes range from 0.0834 to 2.4380, from 0.6650 to 1.2120, from 0.6377 to 1.6050, from 0.5725 to 1.0000, and from 0.1111 to 1.5056, respectively (Table 11). Except for fresh carrots whose expenditure elasticity estimates were mainly insignificant, our expenditure elasticity estimates for celery ($\hat{e}_2 = 0.9402$), lettuce ($\hat{e}_3 = 1.1159$), onions ($\hat{e}_4 = 1.2026$), and tomatoes ($\hat{e}_5 = 1.1285$) (Table 9) fall within or close to the ranges reported by previous studies (Table 11). Overall expenditure elasticity estimates for fresh vegetables range from 0.0834 for fresh carrots in You et al. (1996) to 2.4380 for fresh carrots in Naanwaab and Yeboah (2012) (Table 11), while in this study range from 0.1936 for fresh tomatoes sold by ounce to 1.7411 for fresh precut salad mix sold by ounce (Table 10).

Table 11. Marshallian own-price and expenditure elasticity estimates for fresh-vegetables in previous studies.

Study	Model	Period	Commodity	Market	Marshallian Own-Price	Exp.
Naanwaab and Yeboah (2012)	LA/AIDS	1970-2010	Fresh Carrots	US	-0.2970*	2.3460*
Naanwaab and Yeboah (2012)	LA/AIDS	2010	Fresh Carrots	US	-0.2420*	2.4380*
You et al. (1996)	Composite	1960-1993	Carrots	US	-0.4258*	0.0834
Henneberry et al. (1999)	LA/AIDS	1970-1992	Fresh Carrots	US	-1.6530*	n.a.
Naanwaab and Yeboah (2012)	LA/AIDS	1970-2010	Fresh Celery	US	-0.1000*	0.7540*
Naanwaab and Yeboah (2012)	LA/AIDS	2010	Fresh Celery	US	0.2210*	0.6650*
You et al. (1996)	Composite	1960-1993	Celery	US	-0.0501	1.2120*
Naanwaab and Yeboah (2012)	LA/AIDS	1970-2010	Fresh Lettuce	US	-0.3660*	1.3850*
Naanwaab and Yeboah (2012)	LA/AIDS	2010	Fresh Lettuce	US	-0.0470	1.6050*
You et al. (1996)	Composite	1960-1993	Lettuce	US	0.0032	0.6377
Naanwaab and Yeboah (2012)	LA/AIDS	1970-2010	Fresh Onions	US	-0.2020*	0.7720*
Naanwaab and Yeboah (2012)	LA/AIDS	2010	Fresh Onions	US	-0.2680*	0.7920*
Seale et al. (2013)	Rotterdam	1989-2009	Fresh Onions	MEX Imp.	n.a.	0.9100[a]
Seale et al. (2013)	Rotterdam	1989-2009	Fresh Onions	CAN Imp.	n.a.	1.0000[a]
Henneberry et al. (1999)	LA/AIDS	1970-1992	Fresh Onions	US	-0.2890*	n.a.
You et al. (1996)	Composite	1960-1993	Onions	US	-0.1832*	0.5725
Naanwaab and Yeboah (2012)	LA/AIDS	1970-2010	Fresh Tomatoes	US	-0.4430*	0.6870*
Naanwaab and Yeboah (2012)	LA/AIDS	2010	Fresh Tomatoes	US	-0.5970*	0.7330*
Nzaku and Houston (2009)	LA/AIDS	1989-2008	Fresh Tomatoes	Imp.	-0.5438[a]	0.1111[a]
Nzaku and Houston (2009)	LA/AIDS	1989-2008	Fresh Tomatoes	US	-1.1948[a]	1.5056[a]
Seale et al. (2013)	Rotterdam	1989-2009	Fresh Tomatoes	MEX Imp.	n.a.	1.1800[a]
Seale et al. (2013)	Rotterdam	1989-2009	Fresh Tomatoes	CAN Imp.	n.a.	0.7800[a]
Jung et al. (2005)	double-log	1990-2001	Fresh Tomatoes	US & Imp.	-0.6140*	0.7702*
Jung et al. (2005)	Rotterdam	1990-2001	Fresh Tomatoes	US & Imp.	-0.8468*	1.0640*
Jung et al. (2005)	FD/AIDS	1990-2001	Fresh Tomatoes	US & Imp.	-1.1967*	1.5047*
Henneberry et al. (1999)	LA/AIDS	1970-1992	Fresh Tomatoes	US	-0.2300*	n.a.
You et al. (1996)	Composite	1960-1993	Tomatoes	US	-0.4050*	0.7978*

Note: Significance at the 0.10 probability levels are indicated by asterisk (*).

[a] Statistical significance was not reported.

CONCLUSION AND DISCUSSION

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 total consumption and seventh in per-capita terms (FAOSTAT 2015). 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% (FAOSTAT 2015).

In the world market, tomatoes have the largest volume share (62%) followed by carrots (13%), lettuce (10%), cauliflower (8%), spinach (6%), and onions (2%) (FAOSTAT 2015). In the DFW 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%) (Table 4). 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%) (Table 4). In terms of sales ($), the sales shares are consistent with volume shares when considering fresh vegetable sold by count, but they change slightly when considering fresh vegetables sold by ounce (Table 4). Overall, in terms of sales in dollars, 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%) (Table 4).

With the DFW metropolitan area enjoying healthy production agriculture, growing vegetables in this region becomes increasingly attractive. Not only the number of farms and farmland have increased in the DFW metropolitan area; but there are also more than thirty farmers' markets and several small acreage farms located in urban areas which allow for "agri-entertainment" such as winery farms offering festivals, pumpkin farms allowing Halloween shopping, pasture farms allowing hayrides, corn farms doing corn mazes, and cut-your-own Christmas trees allowing for sleigh rides and ornament making (Bennett and Hanselka 2013). As world vegetable consumption increases, it is important for vegetable producers to keep up with and understand global and local markets. The information provided in this study may assist vegetable growers who sell to grocery chains, farmers' markets, and food service providers in better understanding emerging consumption trends and substitution patterns, and may also provide insight on produce marketability.

Marshallian price elasticities and expenditure elasticities were estimated for fresh vegetables sold by ounce and by count. Among the fresh vegetables sold by ounce, onions have the most inelastic elasticity of demand while carrots have the most elastic. Among the fresh vegetables sold by count, lettuce has the most inelastic elasticity of demand while celery has the most elastic. The 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 fresh vegetables are sold by ounce, which means that retailers may be able to keep fresh-vegetable-market shares relatively more stable by selling by ounce rather than by count when vegetable prices are changing.

Similar to Naanwaab and Yeboah (2012), this study found that consumers are not only responsive to changes in own-prices but also responsive to prices of other fresh vegetables (substitutes or complements). Unlike Naanwaab and Yeboah (2012), this study found about as many negative cross-price elasticities as there are positive cross-price elasticities in the case of fresh vegetables sold by count, and twice as many positive cross-price elasticities than negatives in the case of fresh vegetables sold by ounce. In general, cases of complementary vegetables seem to predominate when analyzing Marshallian cross-price elasticity estimates (e.g., Naanwaab and Yeboah 2012; Henneberry et al. 1999).

Finally, this study used a demand system approach to estimate price and expenditure elasticities for several fresh vegetables using home-scan consumption data from The Nielsen Company for the DFW grocery market in 2012. One of the major limitations of the study is that, due to financial constraints, only one year of data was used in the estimation of the model. Readers should be aware of the limitations of using a model to make predictions or conclusions outside the scope of the data used in the estimation of the model. However, 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 DFW metropolitan area and combine it with data from local production practices to conduct a profitability analysis.

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