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U.S. Import Demand and Supply Response for Fresh Tomatoes, Cantaloupes, Onions, Oranges, and Spinach

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Elasticities of import demand and supply often drive economic models, but few empirical estimates of these elasticities exist for vegetables and fruits. For those that do exist, most are outdated. Because elasticities change over time as income, prices, and market conditions change, outdated elasticity estimates may not be representative of changes in import quantities demanded or in acreages, yield, and quantities supplied. Moreover, import demand elasticities by country of origin for most vegetables and fruits are nonexistent. This article presents research that updates elasticity estimates for each of the selected product categories and includes production and trade implications.

Key Words: acreage response, cointegration, error–correction model, fruits, import demand, Rotterdam model, supply response, vegetables

JEL Classifications: F14, Q11, Q17

Although elasticities of import demand and supply often literally drive economic models, there are few empirical estimates of these elasticities, especially for vegetables and fruits. For those that do exist, most are outdated. This is generally a problem because we expect elasticities to change over time as income, prices, and market conditions change so that outdated elasticity estimates may not be representative of changes in import quantities demanded or in acreages, yield, and quantities supplied. Furthermore, the world has become more global, and the U.S. import market for vegetables and fruits is no exception. However, import demand elasticities by country of origin for most vegetables and fruits are nonexistent.

During the last two decades, U.S. per-capita fresh fruit and vegetable consumption has grown substantially (Huang and Huang, 2007). Also during this period, the import share of most fruits has increased. For example, the import share of fresh oranges in domestic consumption has increased from 1% to 4% between 1993–1995 and 2003–2005.

The same pattern holds for vegetables, which have grown faster in terms of per-capita consumption than have fruits (Huang and Huang, 2007). The import share of fresh tomatoes in domestic consumption has increased from 24% in 1993–1995 to 35% in 2003–2005, whereas the import share of cantaloupes in domestic consumption has increased from 23% in 1993–1995

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to 32% in 2003–2005. The import share of spinach has increased from 1% to 4% between 1993–1995 and 2003–2005.

In terms of growth in U.S. per-capita consumption between 1993–1995 and 2003–2005, fresh orange consumption has decreased by 12%, whereas tomato consumption has increased by 23%, cantaloupe consumption by 18%, and spinach consumption by 185%.[1] How increasing demand coupled with increasing import share affects domestic producers is an important question for those in these industries and for policymakers responsible for food, nutrition, and agricultural policies.

To assist in answering this question, this article presents results of research designed to update econometric parameter estimates for each of the selected product categories (i.e., fresh tomatoes, cantaloupes, fresh onions, oranges, and spinach) and includes production and trade implications. Import demand elasticities are estimated using the systems approach to import demand. Acreage, yield, and quantity supplied elasticities are also estimated. These estimates provide updated expenditure and price sensitivity measures that may be incorporated into econometric models that capture the predicted effects of new regulations and further inflows of imported vegetables and fruits.

Import Demand for Fruits and Vegetables

Few empirical studies estimate the import demand for fruits and vegetables. A number of studies estimate import demand for aggregate fruits or vegetables. For example, Sarris (1979) analyzes income and price elasticities of demand for five categories of fruits and vegetables in the European Union (EU), and Sarris (1983) estimates EU import demand for 10 aggregate categories of fruits and vegetables.

A few more studies have estimated import demand for specific groups of commodities. Roberts and Cuthbertson (1972) analyze market potential for Australian apples in the United Kingdom. Lee, Seale, and Jierwiriyapant (1990) study the import demand for five fruits (oranges, lemons and limes, grapefruit, bananas, and pineapples) in the Japanese market. Lee, Brown, and Seale (1992) analyze Canadian import demand for four fruits (oranges, grapefruit, apples, and bananas) and three juices (orange juice, apple juice, and tomato juice). Schmitz and Seale (2002) analyze the import pattern of Japan's seven most popular fresh fruits (bananas, grapefruit, oranges, lemons, pineapples, berries, and grapes) by testing a general differential demand system, and Seale et al. (2005) estimate Japanese import demand for five fresh fruit categories (bananas, grapefruit, oranges, lemons, and other fruit). Nzaku, Houston, and Fonsah (2010) estimate U.S. import demand for ten tropical fruits and vegetables (bananas, pineapples, papayas, mangos, grapes, avocadoes, tomatoes, peppers, cucumbers, and asparagus). Tshikala and Fonsah (2012) investigate the U.S. import demand of three fresh melons (cantaloupes, watermelons, and other fresh melons) and frozen melons using quarterly data on import volumes and unit prices.

A smaller body of literature exists on the import demand for a specific fruit or vegetable by country of origin. Lee, Seale, and Jierwiriyapant (1990) estimate the Japanese import demand for citrus juices from the United States, Israel, Argentina, Brazil, and the rest of the world (ROW). Seale, Sparks, and Buxton (1992) estimate import demand of U.S. fresh apples in four markets (United Kingdom, Canada, Hong Kong, and Singapore) important to U.S. apple exporters using a Rotterdam import allocation model. Sparks (1992) investigates import demand of U.S. fresh oranges in Canada, the EU, Singapore, and Hong Kong. Seale et al. (2005) estimate Japanese import demand by country of origin for bananas and grapes.

Rotterdam Import Model

The Rotterdam model is developed by Theil (1965) as a system of demand equations derived from the differential approach. The Rotterdam model may also be used as an import demand system for the same commodity from different country sources (Seale, Sparks, and Buxton,

[1] These percentages are calculated from figures presented in Table 3 of Huang and Huang (2007).

1992). The conditional Rotterdam import demand model of an importing country in this case may be written as:

$$(1) \quad w_{ict} d \log q_{ict} = \theta_{ic} DQ_{it} + \sum_{c} \pi_{ijc} d \log p_{jct} + e_{ict},$$

where q_{ict} is the quantity of a fruit or vegetable i imported from exporting country c in time period t, p_{jct} is the price of the fruit or vegetable j from exporting country c in period t, $w_{ict} = (s_{ict} + s_{ic,\, t-1})/2$where s_{ict} is the expenditure share for the fruit or vegetable i from export country c in time period t, $d \log q_{ict} = \log(q_{ict}/q_{ic,\, t-1})$, $d \log p_{jct} = \log(p_{jct}/p_{jc,\, t-1})$, $DQ_{it} = \sum_c w_{ict} d \log q_{ict}$ is the Divisia volume index of fruit or vegetable i, and e_{ict} is the disturbance term. The parameters θ_{ic} (conditional marginal expenditure share) and π_{ijc} (Slutsky compensated price term) are coefficients to be estimated. These coefficients obey the following basic properties:

$$(2a) \quad \text{Adding-up} \sum_{c} \theta_{ic} = 1 \quad \text{and} \quad \sum_{j} \pi_{ijc} = 0,$$

$$(2b) \quad \text{Homogeneity} \sum_{c} \pi_{ijc} = 0, \quad \text{and}$$

$$(2c) \quad \text{Symmetry } \pi_{ijc} = \pi_{icj}.$$

Conditional expenditure and price elasticities (compensated and uncompensated) are calculated as:

(3a) $\eta_{ic} = \theta_{ic}/w_{ic}$ Conditional expenditure elasticity;

(3b) $\varepsilon_{ijc}{}^* = \pi_{ijc}/w_{jc}$ Conditional Slutsky compensated price elasticity; and

(3c) $\varepsilon_{ijc} = (\pi_{ijc}/w_{ij}) - w_{ic}\eta_{ij}$ Conditional Cournot uncompensated price elasticity.

Import Data

U.S. import expenditure data related to volume and price of fruits and vegetables are collected from the U.S. Department of Agriculture (USDA) and U.S. Department of Commerce (USDC). The data sources of fresh tomatoes, cantaloupes, and fresh onions are from the USDC, U.S. Census Bureau (2012c, 2012a, 2012b, respectively). The data on spinach are from the USDC and U.S. International Trade Commission (2012a, 2012b). The import data source of fresh oranges is the USDA, Foreign Agricultural Service (2013). The periods of analysis are 1989–2009 (fresh tomatoes), 1989–2010 (cantaloupes and fresh onions), 1989–2011 (fresh oranges), and 1992–2011 (spinach). Major exporting countries in 2009 of the five commodities are listed in Table 1 in descending order in terms of quantities exported to the United States.

One of the salient facts concerning imported vegetables and fruits into the United States is that the countries that provide these specialty crops are few in number. For example, in 2009, 99% of fresh tomatoes imported into the United States was from Mexico and Canada, 97% of cantaloupes imported into the United States was from three countries (i.e., Guatemala, Honduras, and Costa Rica), 95% of fresh onions was from Mexico, Peru, and Canada, 97% of fresh oranges imported was from four countries (i.e., South Africa, Australia, Chile, and Mexico), and 73% of spinach was from Mexico.

Results

The import demands of fresh tomatoes, cantaloupes, fresh onions, fresh oranges, and spinach by country of origin are estimated using the yearly time-series data described previously. The model fit to the data is the Rotterdam import demand model.[2] Conditional expenditure, Slutsky-own price, and Slutsky cross-price elasticities are calculated from the demand system parameters.

Parameter Estimates

A four-equation-import-demand system is estimated for fresh tomatoes (1989–2009), cantaloupes (1989–2010), fresh onions (1989–2010), and oranges (1989–2011) and a two-equation import demand system is estimated for spinach for the years 1992–2011. The conditional price

[2] We also estimate the import demand system using the CBS model and results are available on request.

Table 1. U.S. Import Quantity, Value, and Quantity Share for Selected Crops by Country of Origin, 2009

Country	Quanlity (1000 pounds)	Value (1000 dollars)	Share
	Fresh Tomatoes		
Mexico	2,307,948	1,125,527	88.0%
Canada	287,285	255,521	11.0
The Netherlands	11,702	12,500	0.4
Dominican Republic	6310	2879	0.2
World	2,622,619	1,403,583	
	Cantaloupes		
Guatemala	527,400	87,382	50.5
Honduras	295,616	23,127	28.3
Costa Rica	192,138	30,261	18.4
Mexico	28,933	7035	2.8
Canada	796	144	0.1
World	1,045,026	147,981	
	Fresh Onions		
Mexico	411,405	170,990	62.8
Peru	145,146	22,381	22.2
Canada	65,579	17,272	10.0
Chile	17,085	4369	2.6
China (Mainland)	6527	1729	1.0
World	655,257	219,745	
	Fresh Oranges		
South Africa	60,066	30,688	29.1
Australia	51,776	30,747	25.1
Chile	44,780	20,020	21.7
Mexico	42,503	8936	20.6
Dominican Republic	4312	1071	2.1
World	206,237	92,913	
	Spinach		
Mexico	7565	3392	72.6
Rest of the World	2860	2657	27.4
World	10,425	6,049	

Source: Economic Research Service, U.S. Department of Agriculture.

parameters and expenditure are estimated and tabulated in Table 2.

The conditional expenditure parameters measure the marginal share of expenditure on imports from exporting countries. For tomatoes, Mexico has the largest marginal share (0.95) followed by The Netherlands (0.03), Canada (0.02), and ROW (0.00). These results indicate if U.S. total import expenditure on fresh tomatoes increases by $1.00 U.S., the expenditure on imports from Mexico increases by $0.95, from The Netherlands by $0.03, and from Canada by $0.02. Mexico has the largest marginal shares for all commodities, and its marginal shares are greater than half except for fresh oranges (0.30).

The own-price parameters of the five commodities from all sources are negative except that of ROW for cantaloupes and all are less than one absolutely. The Slutsky cross-price parameters indicate whether the same commodity imported from different countries is a substitute or complement dependent on the sign of the parameters. If negative, commodity pairings are complements; if positive, they are substitutes. For fresh tomato imports, all country pairings

Table 2. Conditional Parameter Estimates for U.S. Import Demand for Selected Crops from Selected Countries

Fresh Tomatoes, 1989–2009

	Parameters				
	Price (π_{ijc})				
Country (1)	Mexico (2)	Canada (3)	The Netherlands (4)	ROW[b] (5)	Marginal Shares (θ_{ic}) (6)
Mexico	−0.022	0.008	0.002	0.012	0.946
	(0.031)[a]	(0.025)	(0.016)	(0.007)	(0.034)
Canada		−0.062	0.028	0.027	0.019
		(0.035)	(0.027)	(0.013)	(0.029)
The Netherlands			−0.015	−0.016	0.031
			(0.027)	(0.011)	(0.016)
ROW[b]				−0.023	0.004
				(0.007)	(0.007)

Cantaloupes, 1989–2010

	Parameters				
	Price (π_{ijc})				
Country (1)	Mexico (2)	Honduras (3)	Costa Rica (4)	ROW[b] (5)	Marginal Shares (θ_{ic}) (6)
Mexico	−0.088	0.034	0.077	−0.023	0.596
	(0.068)[b]	(0.024)	(0.036)	(0.047)	(0.140)
Honduras		−0.078	0.013	0.032	0.016
		(0.031)	(0.023)	(0.037)	(0.049)
Costa Rica			−0.028	−0.062	0.128
			(0.038)	(0.045)	(0.079)
ROW[b]				0.053	0.260
				(0.076)	(0.093)

Fresh Onions, 1989–2010

	Parameters				
	Price (π_{ijc})				
Country (1)	Canada (2)	Mexico (3)	Chile (4)	ROW[b] (5)	Marginal Shares (θ_{ic}) (6)
Canada	−0.057	0.009	0.019	0.029	0.089
	(0.022)[b]	(0.020)	(0.014)	(0.015)	(0.026)
Mexico		−0.065	0.051	0.005	0.725
		(0.044)	(0.016)	(0.025)	(0.058)
Chile			−0.053	−0.017	0.056
			(0.016)	(0.012)	(0.021)
ROW[b]				−0.017	0.130
				(0.020)	(0.035)

Table 2. Continued

Fresh Oranges, 1989–2011

	Parameter				
	Price (π_{ijc})				
Country (1)	Australia (2)	Mexico (3)	Dominican Republic (4)	ROW[b] (5)	Marginal Shares (θ_{ic}) (6)
Australia	−0.328	0.119	−0.000	0.233	0.180
	(0.118)[b]	(0.057)	(0.004)	(0.118)	(0.157)
Mexico		−0.098	0.031	−0.053	0.304
		(0.051)	(0.012)	(0.052)	(0.077)
Dominican Republic			−0.015	−0.016	−0.009
			(0.011)	(0.007)	(0.007)
ROW[b]				−0.141	0.526
				(0.065)	(0.092)

Spinach, 1992–2011

	Price (π_{ijc})		
Country (1)	Mexico (2)	ROW[b] (3)	Marginal Shares (θ_{ic}) (4)
Mexico	−0.079	0.079	0.773
	(0.065)[b]	(0.065)	(0.083)
ROW[b]		−0.079	0.227
		(0.065)	(0.083)

[a] Asymptotic standard errors are in parentheses.
[b] ROW, rest of world.

are substitutes except that of The Netherlands–ROW, and for fresh onions all are substitutes except Chile–ROW. For cantaloupes, three of the six pairings are substitutes. The same is true for fresh oranges.

Conditional Expenditure Elasticities

The conditional expenditure elasticities of the five commodities are reported in column two of Table 3. These elasticities measure the percent change in quantity demanded of the commodities by place of production from a 1% increase in total import expenditure for the commodity. If the elasticity is less than one, it is inelastic and indicates that the import share of the country for the commodity decreases if total expenditure for the commodity increases.

If a conditional expenditure elasticity is higher than one, it is conditionally elastic and indicates that the import share from that country of the commodity increases as total import expenditure on this commodity increases. Mexico's expenditure elasticities are elastic for fresh tomatoes (1.2), cantaloupes (2.2), fresh oranges (2.2), and spinach (1.1). Other countries with elastic expenditure elasticities are Chile for fresh onions (2.3), ROW for fresh onion (1.4) and fresh oranges (1.4). These countries stand to benefit most from an increase in import expenditures for the commodities.

Slutsky Own-Price Elasticities

The Slutsky own-price elasticity measures the percent change of quantity demanded from an importing country of a commodity for a 1% increase in own price. All own-price elasticities are negative for all selected commodities from all sources except that of ROW for cantaloupes. Generally, they are inelastic (less than one, absolutely) except Chile for fresh onions (−2.2) and ROW for fresh tomatoes (−1.3). The larger the absolute value of the own-price elasticity,

Table 3. Conditional Expenditure and Slutsky (compensated) Price Elasticities of U.S. Import Demand for Fresh Tomatoes, Cantaloupes, Onions, Oranges, and Spinach from Selected Countries

Fresh Tomatoes, 1989–2009

Country	Expenditure Elasticities	Own-Price Elasticities	Cross-Price Elasticities			
			Mexico	The Netherlands	Canada	ROW[a]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Mexico	1.18	−0.03	—	0.01	0.00	0.01
The Netherlands	0.14	−0.44	0.05	—	0.20	0.19
Canada	0.78	−0.37	0.06	0.70	—	−0.40
ROW[a]	0.21	−1.28	0.64	1.51	−0.88	—

Cantaloupes, 1989–2010

Country	Expenditure Elasticities	Own-Price Elasticities	Cross-Price Elasticities			
			Mexico	Honduras	Costa Rica	ROW[a]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Mexico	2.20	−0.32	—	0.12	0.28	−0.08
Honduras	0.11	−0.50	0.21	—	0.08	0.21
Costa Rica	0.53	−0.11	0.32	0.05	—	−0.26
ROW[a]	0.78	0.16	−0.07	0.10	−0.19	—

Fresh Onions, 1989–2010

Country	Expenditure Elasticities	Own-Price Elasticities	Cross-Price Elasticities			
			Canada	Mexico	Chile	ROW[a]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Canada	1.00	−0.64	—	0.10	0.21	0.32
Mexico	0.91	−0.08	0.01	—	0.06	0.01
Chile	2.27	−2.15	0.76	2.08	—	−0.70
ROW[a]	1.39	−0.18	0.31	0.05	−0.18	—

Fresh Oranges, 1989–2011

Country	Expenditure Elasticities	Own-Price Elasticities	Cross-Price Elasticities			
			Australia	Mexico	Dominican Republic	ROW[a]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Australia	0.41	−0.74	—	0.27	−0.00	0.47
Mexico	2.16	−0.70	0.85	—	0.22	−0.37
Dominican Republic	−0.21	−0.34	−0.01	0.71	—	−0.35
ROW[a]	1.40	−0.38	0.56	−0.14	−0.04	—

Spinach, 1992–2011

Country	Expenditure Elasticities	Own-Price Elasticities	Cross-Price Elasticities	
			Mexico	ROW[a]
(1)	(2)	(3)	(4)	(7)
Mexico	1.07	−0.11	—	0.11
ROW[a]	0.81	−0.28	0.28	—

[a] ROW, rest of world.

the more sensitive are imports to an own-price change. Fresh tomatoes from ROW are most sensitive to an own-price change among countries exporting this commodity to the United States. For the other commodities, cantaloupes from Honduras (−0.5), fresh onions from Chile, and fresh oranges from Australia (−0.7) are most own-price sensitive among the countries exporting these products to the United States. Spinach imports are found to be highly own-price inelastic from both Mexico (−0.1) and ROW (−0.3).

Supply Response

Compared with some other agricultural sectors such as dairy, sugar, and cotton, vegetable and fruit production in the United States takes place in an atmosphere with little government intervention. This characteristic of vegetables and fruits calls for estimation of supply response to understand how resources are allocated and how planting decisions are made.

The traditional approach to supply response for individual agricultural commodities involves the use of planted or harvested acreage to represent planned output. Rao (1989) argues that planted acreage as a proxy for output captures farmers' price-based decisions better than harvested acreage or market quantities, because planted acreage is thought to be more subject to farmers' control than output. Lopez and Munoz (2012) divide the supply responses into two representative equations: acreage and yield. Production is then derived as the product of harvested acreage and yield. The combination of production and acreage is another approach to estimate supply response. Instead of using a system of equations, Russo, Green, and Howitt (2008) analyze the production and acreage functions with similar exogenous variables.

According to Ghatak and Seale (2001), supply response can be regarded as a function of a number of controlled variables (e.g., fertilizers, irrigation water, input and output prices or profits, and use of pesticides) as well as uncontrolled variables (e.g., rainfall, temperature, and humidity). Most previous work emphasizes that weather and price movements are responsible for production fluctuations.

Own-output price is frequently used as an exogenous variable in models of supply response. Most time-series studies of supply response report a positive output elasticity for a specific crop with respect to an own-price change, although the degree of effect on supply response is different, dependent on the specification of endogenous variables. For example, a statistical study of the Philippines finds that although acreage elasticities to relative crop prices are significant, yield responses are not (Mangahas, Recto, and Ruttan, 1966). Some studies also show that fruits and vegetables are not responsive to price changes both in the short and long run. Inability of fruit and vegetable growers to respond to prices may be the result of vertical relationships (e.g., production or marketing contracts), which may seriously undermine the competitive nature of the market (Onyango and Bhuyan, 2000).

The prices of inputs facing farmers are an integral aspect of economic incentives for agricultural production. Griliches (1958) finds that in the United States if fertilizer prices rise by 10%, fertilizer use drops by 5% in the first year and by approximately 20% in the long run. The harvest-frequency decision also affects crop yield, because the frequency determines the amount of input applied (Lopez and Munoz, 2012). For example, tomatoes may be picked two to five times depending on the planting technique used. Hence, yield is expected to be inversely related to wage rate, because growers increase (decrease) harvesting frequency as wage rate decreases (increases).

At the state or regional level, weather in terms of rainfall and temperature is often one of the most important variables influencing yield and production of a given crop. The index of weather depends on regions and data availability such as water availability measured by the four-river index (Russo, Green, and Howitt, 2008) or deviations from a normal snowing period (Ghatak and Seale, 2001). At the U.S. level, however, local weather conditions are less convincing in explaining the aggregate domestic supply response.

In terms of model specification, the well-known partial adjustment model has been the dominant approach to analyze agricultural production. According to Nerlove (1956), producers are assumed to adjust their output toward long-run or desired output. Current output is assumed to be a function of past output. This movement toward the long-run equilibrium is determined on the basis of a static theory of optimization, which assumes that future values of the exogenous variables (mainly prices) remain unchanged. However, the assumption of a fixed target is unrealistic in the context of optimization under dynamic conditions and criticized by many economists.

Another major shortcoming of previous studies is the failure to account for the possibility of nonstationarity of time-series data. The existence of nonstationarity invalidates standard statistical tests, resulting in what has become known as a spurious regression (Granger, 1981). The test of stationarity and techniques to correct the nonstationarity is necessary to understand the supply response inherent in time-series data. Our work addresses these shortcomings and investigates the supply response with respect to the short run and the long run.

Method

Acreage, yield, and quantity supplied equations are fit to time-series data. Yule (1926) shows that a spurious correlation in nonstationary time-series data can persist even if the sample is very large. As a result of this concern, we developed a strategy for estimation.

Time-series data may be stationary or nonstationary. Stationary time-series data are characterized by constant means, constant variances, and the value of the covariance between two periods depending only on the gap between the periods and not the actual time of the periods. Nonstationary time-series data will have one or more of these three conditions violated (Charemza and Deadman, 1992, p. 118). The first step in our method is to test whether or not a given time-series variable is nonstationary. This is done by testing for a unit root in the time-series data using the augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979; Engle and Granger, 1987). If the data are stationary, the equation is estimated first with ordinary least squares (OLS) and next with the Prais-Winston transformation for first-order autocorrelation of the error term (Prais and Winston, 1954; Kmenta, 1990, pp. 318–20). A log-likelihood ratio test is performed to choose between the two estimators.

In the case in which the time-series data are found to be nonstationary, a test of cointegration is conducted to check the existence of a long-run equilibrium among the variables in the model. As Granger (1981) notes, "A test for cointegration can be thought of as a pretest to avoid 'spurious regression' situations." This is because, under the condition of nonstationarity, the OLS regression may be spurious. If the time-series are nonstationary but cointegrating, the OLS regression on the nonstationary variables represents the cointegration regression of the long-run relationships of the variables. If the time-series data are nonstationary but are not cointegrating, the OLS regression on the nonstationary variables results in a spurious regression. Accordingly, two estimation methods based on whether or not the time-series variables are cointegrating in the long run are chosen. If we cannot reject cointegration, the error correction model (ECM) is used (Sargan, 1984; Engle and Granger, 1987). If cointegration is rejected, the variables are first differenced and the first-difference model is fit to the data (Maddala and Kim, 1998, p. 24).

The application of ECM captures both short-run dynamics and adjustments toward long-run equilibrium. More specially, the estimates in ECM measure the short-run effects and how quickly the equilibrium is restored, whereas the estimates in the cointegration regression are used to explain the long-run relationships. If first-differenced variables are stationary but not cointegrated, we can take the first difference of the time-series data and estimate the short-term relationships by using the first-difference model. However, problems arise in estimating the long-run relationships because the OLS regression of the nonstationary variables is spurious under this condition.

The ADF test results for all the dependent variables are presented in Table 4. In all cases, these test results do not reject a unit root and thus nonstationarity of the dependent variables

Table 4. Augmented Dickey Fuller Tests Results for Dependent Variables

Crops	Acreage			Yield			Quantity Supplied		
	Test Statistic	5% Critical Value	Years	Test Statistic	5% Critical Value	Years	Test Statistic	5% Critical Value	Years
Tomatoes	−1.931	−2.933	1960–2009	−1.258	−2.933	1960–2009	−1.247	−2.933	1960–2009
Tomatoes	—[a]	—	—	—	—	—	0.638	−2.994	1960–1987
Tomatoes	—	—	—	—	—	—	−2.206	−3.000	1988–2009
Cantaloupes	−1.290	−2.922	1950–2010	−1.368	−2.930	1960–2010	−1.436	−2.950	1967–2010
Fresh Onions	−1.665	−2.922	1950–2010	−0.786	−2.930	1960–2010	−0.707	−2.930	1960–2010
Spinach	—	—	—	—	—	—	−0.955	−3.000	1989–2009

[a] Dash (—) indicates not applicable.

cannot be rejected. The ADF tests (not reported) on the explanatory variables also cannot reject nonstationarity.

Supply Data

Acreage, yield, production, and price data are from the USDA. These data for fresh tomatoes, cantaloupes, and fresh onions are from the USDA, National Agricultural Statistics Service (2012c, 2012a, 2012b, respectively). Data on spinach (Table 2), prices of watermelon (Table 3), and price of leafy lettuce (Table 1) are from Thornsbury, Jerardo, and Wells (2012). Farm wage rate and fertilizer-index data are from the USDA, National Agricultural Statistics Service (2012d, 2012e).

Acreage and yield response equations are fitted to the U.S. data of fresh tomatoes (1960–2009), cantaloupes (1950–2010 for acreage, 1960–2010 for yield), and fresh onions (1950–2010 for acreage, 1960–2010 for yield). In the acreage equations, the log of acreage is regressed on the log of own-price lagged one period, the log of the competing crop's price (i.e., processed tomatoes for fresh tomatoes, watermelons for cantaloupes, but no substitutes for fresh onions), the log of lagged acreage, a time trend, and a constant. In the yield equation, for the same three crops, the log of yield per acreage is regressed on the log of own price, the real wage rate, the log of a fertilizer-price index, a time trend, and a constant. Results of these regressions are reported in Table 5.

Before discussing the results from the acreage and yield response equations, it is first important to discuss the stationarity tests of the residuals of these equations. The ADF test results of the residuals of these regressions are reported in Table 6. If the test statistic is smaller than the critical value of the test at the 5% level, then the unit root in the residuals is rejected and the residuals are considered to be stationary. If so, this indicates that the cointegration regression appropriately reflects the long-run cointegrating relationships among the variables in the equation. All ADF tests of the residuals of the acreage and yield equations indicate stationarity in the residuals and that the variables are cointegrated. As such, the results

Table 5. Cointegration Regression and Ordinary Least Squares Results

Equation/Explanatory Variables	Tomatoes	Tomatoes	Tomatoes	Cantaloupes	Fresh Onions	Spinach
Acreage	1960–2009			1950–2010	1950–2010	
Log own price, lagged	0.159***	—[a]	—	0.139**	0.117***	—
	(0.046)	—	—	(0.065)	(0.029)	—
Log competing crop's price	−0.193[b]***	—	—	−0.061[c]	–	—
	(0.045)	—	—	(0.050)		—
Log acreage, lagged	0.567***	—	—	0.909***	0.783***	—
	(0.107)	—	—	(0.064)	(0.066)	—
Time trend	−0.005***	—	—	−0.002	−0.001	—
	(0.001)	—	—	(0.002)	(0.001)	—
Constant	4.947***	—	—	0.902	2.383***	—
	(1.298)	—	—	(0.777)	(0.770)	—
Yield	1960–2009			1960–2010	1960–2010	
Log own price, lagged	0.339***	—	—	0.183**	−0.018	—
	(0.070)	—	—	(0.084)	(0.022)	—
Wages	−7.191***	—	—	−13.542***	−1.016	—
	(1.506)	—	—	(1.935)	(0.790)	—
Log fertilizer price	0.078	—	—	−0.254***	−0.011	—
	(0.051)	—	—	(0.066)	(0.028)	—
Time trend	0.014***	—	—	0.031***	0.015***	—
	(0.003)	—	—	(0.003)	(0.001)	—
Constant	4.155***	—	—	10.287***	5.626***	—
	(0.191)	—	—	(0.218)	(0.100)	—
Quantity supplied	1960–2009	1960–1987	1988–2009	1967–2010	1960–2010	1989–2009
Log own price, lagged	0.189*	−0.030	0.042	0.031	−0.016	−0.090
	(0.111)	(0.152)	(0.112)	(0.139)	(0.042)	(0.235)
Log competing crop's price	−0.126[b]	−0.190[b]**	−0.467[b]***	−0.074[c]	—	−0.458[d]**
	(0.096)	(0.083)	(0.126)	(0.132)		(0.211)
Log imports	−0.324***	−0.383***	−0.097	0.191*	0.109**	0.184**
	(0.052)	(0.052)	(0.061)	(0.101)	(0.045)	(0.077)
Time trend	0.027***	0.047***	0.007	0.007	0.020***	0.056***
	(0.004)	(0.006)	(0.006)	(0.009)	(0.003)	(0.013)
Constant	3.336***	2.757***	7.799***	7.930***	9.164***	5.385***
	(0.312)	(0.256)	(0.677)	(0.593)	(0.225)	(0.906)

[a] Dash (—) indicates not applicable.
[b] Log of processed tomato price.
[c] Log of watermelon price.
[d] Log of lettuce price.
*** Significance at 0.01; ** significance at 0.05; * significance at 0.10.

reported in Table 5 for acreage and yield represent the long-run relationships of the variables.

Acreage and Yield Responses

The long-run own-price elasticities from the three acreage-response equations are all positive, significant statistically at least at the 5% level, and are all similar in size with the smallest for fresh onions and the largest for fresh tomatoes. The estimates indicate that a 1% increase in own price will increase acreage allocated to the crop by 0.16% for fresh tomatoes, by 0.14% for cantaloupes, and by 0.12% for fresh onions. The fresh tomato acreage elasticity with respect to the price of processed

Table 6. Augmented Dickey Fuller Tests Results for Residuals of Cointegration Regressions

	Acreage			Yield			Quantity Supplied		
Crops	Test Statistic	5% Critical Value	Years	Test Statistic	5% Critical Value	Years	Test Statistic	5% Critical Value	Years
Tomatoes	−5.205*	−2.936	1960–2009	−3.443*	−2.936	1960–2009	−1.963	−2.936	1960–2009
Tomatoes	—[a]	—	—	—	—	—	−3.332*	−2.997	1960–1987
Tomatoes	—	—	—	—	—	—	−3.659*	−3.000	1988–2009
Cantaloupes	−6.641*	−2.923	1950–2010	−4.151*	−2.933	1960–2010	−2.337	−2.952	1967–2010
Fresh Onions	−7.742*	−2.923	1950–2010	−6.707*	−2.933	1960–2010	−4.388*	−2.933	1960–2010
Spinach	—	—	—	—	—	—	−6.072*	−3.000	1989–2009

[a] Dash (—) indicates not applicable.

* Test indicates stationary residuals indicating error–correction mechanism is appropriate.

tomatoes, the competing crop, is negative, statistically significant, and it indicates that fresh tomato acreage will decrease 0.19% if the price of processed tomatoes increases by 1%. The cantaloupe acreage elasticity with respect to watermelon price is negative as expected, but it is not significantly different from zero. The acreage elasticities of all three crops with respect to lagged own-acreage are positive and statistically different from zero. These elasticities indicate that a 1% increase in own acreage in the prior period will result in an increase of acreage in the current period by 0.57%, 0.91%, and 0.78%, respectively, for fresh tomatoes, cantaloupes, and fresh onions. It is also noteworthy that the time trends of all three crops are negative, but the coefficient on the time trend is only statistically significantly different from zero in the tomato acreage equation.

For the yield per-acre equations, it is expected that the log of own price will have a positive coefficient, real wages a negative coefficient, and log of the fertilizer-price index a negative coefficient. The coefficients on the log of own price for tomato and cantaloupe yield per acre are positive and statistically significant indicating that a 1% increase in own price of fresh tomatoes and cantaloupes will increase yield per acre by 0.34% and 0.18%, respectively. This is because, as own price increases, farmers more intensively harvest these crops. The coefficient on the own price of fresh onions is negative but statistically the same as zero. All the coefficients on real wage are negative as expected, and those of fresh tomatoes and cantaloupes are statistically significant. This indicates that the yields per acre of fresh tomatoes and cantaloupes that have labor-intensive harvest processes are highly sensitive to real wage. A 1% increase in real wage will decrease the yield per acre of fresh tomatoes and cantaloupe by 7.19% and 13.4%, respectively. The coefficient on the log of fertilizer-price index for cantaloupes is negative and statistically significant. This indicates that a 1% increase in the fertilizer-price index will decrease the yield per acre of cantaloupes by 0.25%. The coefficients on the trend variable for all three crops are positive and statistically different from zero.

These elasticities are long-run elasticities. Short-run elasticities for the acreage and yield per acre equations are obtained from the ECM regressions and are presented in Table 7 along with standard errors. For acreage, the short-run own-price elasticities for fresh tomatoes and fresh onions are positive and statistically significant, whereas that for cantaloupe acreage is positive but insignificant. These results indicate that the short-run adjustments of tomato and fresh onion acreage are 0.21% and 0.13%, respectively, for a 1% increase in own price. The short-run elasticities of acreage with respect to competing price of fresh tomatoes (processed tomatoes) and cantaloupes (watermelons) are negative as expected and significantly different

Table 7. Error–Correction Model and First-Difference Model Results

Equation/Explanatory Variables	Tomatoes	Tomatoes	Tomatoes	Cantaloupes	Fresh Onions	Spinach
Acreage	1960–2009			1950–2010	1950–2010	
ΔLog own price, lagged	0.209***	—[a]	—	0.003	0.126***	—
	(0.047)			(0.081)	(0.022)	
ΔLog competing crop's price	−0.211[b]***	—	—	−0.179[c]***	–	—
	(0.054)			(0.051)		
ΔLog acreage	0.755***	—	—	0.966***	0.398***	—
	(0.194)			(0.363)	(0.126)	
Constant	−0.004	—	—	0.007	0.002	—
	(0.006)			(0.010)	(0.006)	
Residual, lagged	−0.905**	—	—	−0.997***	−0.445***	—
	(0.245)			(0.371)	(0.151)	
Yield	1960–2009			1960–2010	1960–2010	
ΔLog own price, lagged	0.007	—	—	0.168*	−0.004	—
	(0.069)			(0.088)	(0.023)	
ΔWages	0.881	—	—	−4.980	0.285	—
	(2.604)			(3.996)	(1.942)	
ΔLog fertilizer price	0.078	—	—	−0.272***	−0.003	—
	(0.063)			(0.101)	(0.050)	
Constant	0.014*	—	—	0.020	0.013*	—
	(0.008)			0(.013)	(0.007)	
Residual, lagged	−0.239*	—	—	−0.495***	−0.944***	—
	(0.122)			(0.137)	(0.162)	
Quantity supplied	1960–2009	1960–1987	1988–2009	1967–2010	1960–2010	1989–2009
ΔLog own price, lagged	0.101	0.127	0.040	0.164*	0.097**	−0.346**
	(0.063)	(0.121)	(0.074)	(0.097)	(0.039)	(0.158)
ΔLog competing crop's price	−0.104[b]	−0.117[b]	−0.405[b]*	−0.228[c]***	—	−0.207[d]
	(0.07)	(0.071)	(0.196)	(0.078)		(0.130)
ΔLog imports	−0.161***	−0.197***	−0.125**	0.122	−0.003	0.073
	(0.036)	(0.058)	(0.049)	(0.080)	(0.034)	(0.079)
Constant	0.0167**	0.026**	0.005	0.006	0.021**	0.051**
	(0.008)	(0.011)	(0.011)	(0.015)	(0.009)	(0.026)
Residual, lagged	—	−0.366*	−0.744**	—	−0.376**	−1.30***
		(0.195)	(0.270)		(0.153)	(0.216)

[a] Dash (—) indicates not applicable.
[b] Log of processed tomato price.
[c] Log of watermelon price.
[d] Log of lettuce price.
*** Significance at 0.01; ** significance at 0.05; * significance at 0.10.

from zero. The short-run response of fresh tomato acreage and cantaloupe acreage to a 1% increase in the price of the competing crop is a decrease in acreage by 0.21% and 0.18%, respectively. The short-run elasticities of acreage to a change in the previous periods acreage allocated to the crops are all positive and statistically significant. Cantaloupe acreage has the largest response followed by fresh tomato and fresh onion acreage. None of the constants that represent time trends are statistically significant. The coefficients on the error–correction term are all negative and statistically different from zero. These coefficients indicate the speed of adjustment for acreage of these crops to return to a long-run equilibrium when in disequilibrium. Cantaloupe acreage responds most quickly followed by fresh tomato acreage and fresh onion acreage. The coefficients indicate that cantaloupe and fresh tomato acreages return to equilibrium almost immediately, whereas acreage of fresh onions takes considerably more time.

The yield coefficients of the ECM are mostly insignificant except for cantaloupe. The coefficient of the own price of cantaloupes is positive, significantly different from zero, and it indicates that yield per acreage will increase in the short run 0.17% for a 1% increase in the price of cantaloupes. The coefficients on the constants of fresh tomatoes and fresh onions indicate there are positive and significant time trends for yield per acre in the short run for these two crops. All the coefficients of adjustment on the error–correction variable are negative; those of the cantaloupe and fresh onion equations are statistically significant at the 1% level and that of the tomato equation at the 10% level. The adjustment coefficient of fresh onions indicates that yield for this crop adjusts toward the long-run equilibrium almost immediately, whereas the adjustment coefficients of the other two crops indicate that the adjustment of cantaloupe yield is slower and that of tomatoes is slowest.

Quantity Supplied

The case for quantity supplied is more complicated and diverse in terms of results than those for acreage and yield per-acre responses. A plot of quantity supplied of fresh tomatoes indicates that the time-series data behave differently between the 1960–1987 period and the 1988–2009 period. To test whether there is a structural change between the two periods, a log-likelihood ratio test is performed. The restricted model is one in which the data are pooled between the two periods and the quantity supplied model fit to that data. The unrestricted model allows the parameters in the two periods to differ, and it is accomplished by multiplying all variables in the model by a dummy variable that is zero for the years 1960–1987 and one for the years 1988–2009. The log-likelihood ratio test rejects the hypothesis that the coefficients are statistically the same in the two periods indicating that the data should not be pooled. Accordingly, the two periods are estimated with the cointegration regression individually, and results are reported in Table 5. Next, the ADF test is used to test for stationarity of the residuals of the cointegration regression (Table 6), and it is found that the residuals of the two periods are both stationary indicating cointegration in both periods but not in the full-sample period. For cantaloupes, a test of stationarity finds that the residuals of the cointegration regression are nonstationary. For fresh onions and spinach, the ADF test of the residuals of the cointegration regression indicates that these equations are cointegrating and that the ECM is appropriate.

These cointegration test results indicate that the quantity supplied regressions of the full sample of tomatoes and of cantaloupe is spurious. Those of the two separate samples of tomatoes, fresh onions, and spinach are not spurious and represent the long-run relationships of the variables. Somewhat surprising, none of the long-run coefficients on the own-price variable are statistically significant at the 5% level. The long-run quantity supplied elasticities with respect to competing crop price are all negative as expected and are statistically significant in three cases: tomatoes 1960–1987, tomatoes 1988–2009, and spinach. The elasticities of fresh tomatoes in 1988–2009 (−0.47) and spinach (−0.46) are of similar size, whereas that of tomatoes in 1960–1987 (−0.19) is less than half the size. All coefficients on the time-trend variables are positive and are statistically significant for fresh tomatoes in 1960–1987, tomatoes in 1988–2009, fresh onions, and spinach.

The most interesting results in terms of quantity supplied concern imports of the tomatoes in the two periods. For both periods, imports of fresh tomatoes have a negative effect but the elasticity of quantity supplied with respect to import quantity is only significantly different from zero in the earlier 1960–1987 period. During this period, domestic producers of fresh tomatoes insist that their industry was being negatively affected by imported fresh tomatoes and the evidence here bears that out. However, during the later period, a voluntary marketing arrangement is agreed on by U.S. and Mexican producers that seemingly stopped the strong negative effect on U.S. fresh tomato producers of imports (VanSickle, Evans, and Emerson, 2003). The import elasticities for fresh onions and spinach are positive and significant, which would suggest that during this period, both domestic production and imports are growing but that imports are not detrimental to these two particular industries.

Short-run elasticities are estimated from the ECM for tomatoes in the two separate periods, for fresh onions and for spinach, whereas short-run elasticities are estimated for the full sample of tomatoes and for cantaloupes from the first-difference model. In the short run, own price has a statistically positive effect on cantaloupes and fresh onions. All the short-run elasticities of quantity supplied with respect to the competing crop price are negative and those of fresh tomatoes in 1988–2009 and of cantaloupes are statistically significant.

The elasticities of quantity supplied of tomatoes with respect to import quantity are negative and significant for all three periods. It is largest (−0.20) for the early period and smallest for the later period (−0.13). The import elasticities are not significant in the short run for the other crops. The constant, indicating a time trend in the short run, is positive in all cases and is statistically different from zero except in the cases of fresh tomatoes in 1988–2009 and of cantaloupes.

The coefficients of adjustment are also reported in Table 7. They are negative in all cases in the ECM (i.e., fresh tomatoes in 1960–1987, tomatoes in 1988–2009, fresh onions, and spinach). The results indicate that spinach adjusts to its long-run equilibrium fastest followed by tomatoes in 1988–2009, fresh onions, and tomatoes in 1960–1987. There are no coefficients of adjustment for the full sample of fresh tomatoes and cantaloupes, because a cointegration relationship is rejected among the variables in the quantity supplied equation.

Conclusions

U.S. import demand by country of origin is estimated for fresh tomatoes, cantaloupes, fresh onions, spinach, and fresh oranges using the differential approach. Conditional expenditure, own-price, and cross-price elasticities of import demand are calculated from the parameters of the models. Additionally, acreage, yield, and quantity supplied equations are estimated using ECM where appropriate and first-difference models otherwise. Supply elasticities are also calculated and discussed.

An important contribution of the article is the estimation of elasticity estimates for these crops. Few elasticity estimates exist for import demand by country of origin or for supply response for individual fruits and vegetables. Those that do exist are generally out of date. Given the important issues facing U.S. specialty-crop producers, it is important to have up-to-date elasticity estimates that may be used to drive economic models that consider effects of imports, environmental regulations, and recently authorized food safety requirements for specialty crops.

Several implications are drawn from the import demand results. The large majority of imports of the five goods originate in a small number of countries. Imports from some countries, particularly Mexico, have conditional expenditure elasticities that are elastic (greater than one). These countries stand to benefit most from increases in imports of these goods in response to rising U.S. consumer incomes. Own-price elasticities of all commodities from each of the major countries that export to the United

States are negative and most are inelastic. If the price of an inelastic good rises, quantity demanded from that country falls, but the reduction is sufficiently inelastic such that exporter revenue increases.

The supply–response findings are equally interesting. Acreage responds positively to changes in own price in the long run for tomatoes, cantaloupes, and fresh onions as does yield for tomatoes and fresh onions. Demand for these crops is expected to rise with increases in U.S. consumer incomes, which would put upward pressure on their prices. If so, acreage allocated to these crops would expand. However, if imports grow rapidly enough, prices could fall and that would decrease acreage planted to these crops.

Except for tomatoes, however, imports are not found to negatively affect quantity supplied in the long or short run. For tomatoes, significant long-run effects of imports on quantity supplied are found in the early period but not for the later period. In the later period, a voluntary market agreement is in place between U.S. and Mexican producers that apparently works in favor of U.S. tomato producers. The short-run effect of imports on quantity supplied of tomatoes, however, is negative and significant in both periods.

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