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The Role of Exchange Rates on Country-Differentiated Demand: The Case of United States Tomatoes

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We develop a framework to incorporate exchange rates into a differential demand system and apply it to U.S. demand for fresh tomatoes by country of origin. We find evidence of incomplete exchange-rate pass-through involving Mexico. Results indicate that accusations of dumping by American agricultural groups in 1995–1996 coincide with the appreciation of the U.S. dollar against the peso in 1994–1995. Traditional modeling approaches that do not account for exchange-rate effects would not capture the distinction between dumping and changes in relative prices, leading to the conclusion that too many tomatoes were being imported from Mexico.

Key words: differential demand systems, dumping, exchange-rate pass-through, international trade, Mexico, NAFTA, suspension agreements

Introduction

Demand for fresh produce has been and continues to be an area of robust research, but one area that has received scant attention is the role that exchange rates and the speed with which they pass through the trade system play in the demand for fresh produce. This analysis extends the differential demand system to incorporate potentially delayed exchange-rate effects. We apply the method to North American demand for fresh tomatoes and the role of exchange rates in U.S. demand for Mexican and Canadian tomatoes.

One would expect that exchange-rate fluctuations among countries would alter U.S. consumer preferences for tomatoes differentiated by country of origin. Changes in exchange rates are driven by many factors, including national policies and the strength of the national currency. A strong domestic currency provides incentives for increased imports, while a weak currency increases the demand for domestic produce.

The North American market for fresh produce, such as tomatoes, is large and highly politicized. The importance of fresh produce in North America and the dynamic changes in exchange rates make it difficult to ascertain how exchange rates and trade flows are related. Early work by Acharya and Schmitz (2004) and Valdez-Lafarga (2015); Valdez-Lafarga and Schmitz (2016) examined this issue in limited ways. The econometric methods developed here generalize the entry of exchange rates into a system of differential demand equations. The work extends the North American tomato analysis of Asci et al. (2016) to accommodate the gradual impact of exchange rates on the tomato trade.

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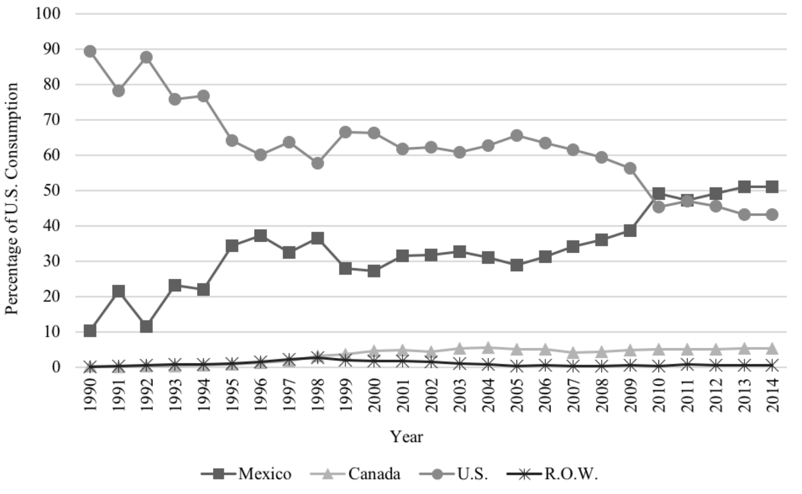

Figure 1. Market Share by Country for U.S. Tomato Market, 1990–2014

Sources: U.S. Department of Commerce (2014), Thornsbury and Bond (2015).

Contextual Background

Tomatoes are the highest-valued fresh produce in the United States. Between the early 1990s and 2009, U.S. tomato imports increased by 20% (Thornsbury, 2012). Imported tomatoes accounted for, on average, approximately 37% of U.S. tomato consumption over that period. Prior to 2010, domestically produced tomatoes held a larger U.S. market share than imports, but since 2010, Mexican imports have held the largest share of the market (Figure 1).

Improved production technologies are one important factor driving the increasing Mexican share of the U.S. tomato market. These have led to improved quality and food safety (Thornsbury, 2012), which make Mexican tomatoes more attractive to U.S. consumers. Although Mexican tomatoes have the largest market share in terms of volume (for the 1990–2014 period), they do not receive the highest prices in the U.S. market. Currently, U.S. domestic tomatoes receive the lowest prices, followed by Mexican tomatoes (Figure 2). Canadian and other countries' tomatoes receive the highest prices by a fair margin (U.S. Department of Commerce, 2014; Thornsbury and Bond, 2015).

U.S. domestic tomato prices increased from $0.26/kg in 1990 to S$0.96/kg in 2014 (Figure 2). Over the same period, Mexican tomatoes hovered around $1.00/kg. The price of Canadian tomatoes has risen more or less continually since 1993, reaching around $1.86/kg in 2014. The price of ROW tomatoes increased from less than $1.00/kg to a peak of $1.94/kg in 2006, falling back down to about $1.42/kg in 2014.

Mexican tomatoes compete with domestic tomatoes produced in Florida during the winter and early summer season (October–June). Mexican produce is grown primarily in the state of Sinaloa, with production peaks in the winter and early spring months (December–April). Production then decreases from May to June as the season comes to an end. Florida tomatoes experience peak production in April and May, and the season ends in June (Thornsbury, 2012). Mexican tomatoes are shipped mostly to the western United States, while Florida tomatoes are shipped mostly to the eastern United States. Mexican tomatoes account for 43%–68% of the U.S. market during their production peak (Cook and Calvin, 2005). While U.S. tomato production has remained at roughly the same level between 1991 and 2014 (Figure 3), imports have increased steadily over the same period (U.S. Department of Commerce, 2014; Thornsbury and Bond, 2015).

U.S. tomato production fluctuated between 1.2 million and 1.6 million metric tons between 1990 and 2014 (Figure 3). The highest level of U.S. tomato production was in 2005 (1.8 metric tons). Over the same period, U.S. tomato imports increased from 0.4 million to almost 1.6 million metric tons.

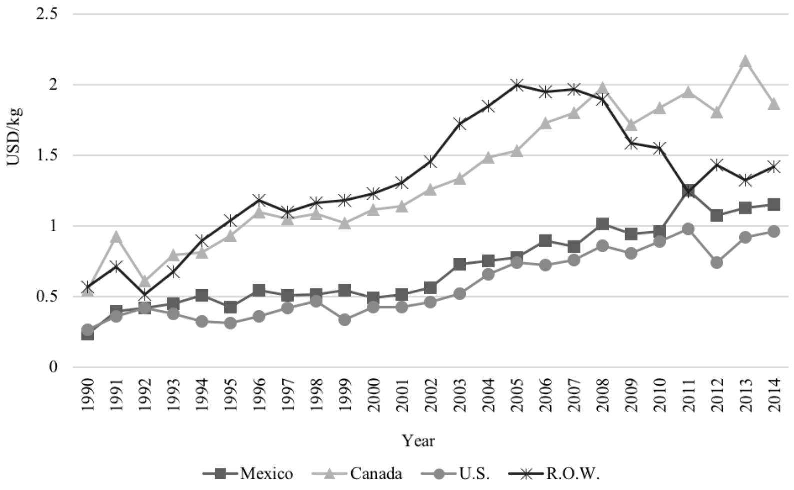

Figure 2. Prices Received by Country for Tomatoes in the U.S. Market, 1990–2014 (in real 2017 U.S. dollars/kg)

Sources: U.S. Department of Commerce (2014), Thornsbury and Bond (2015).

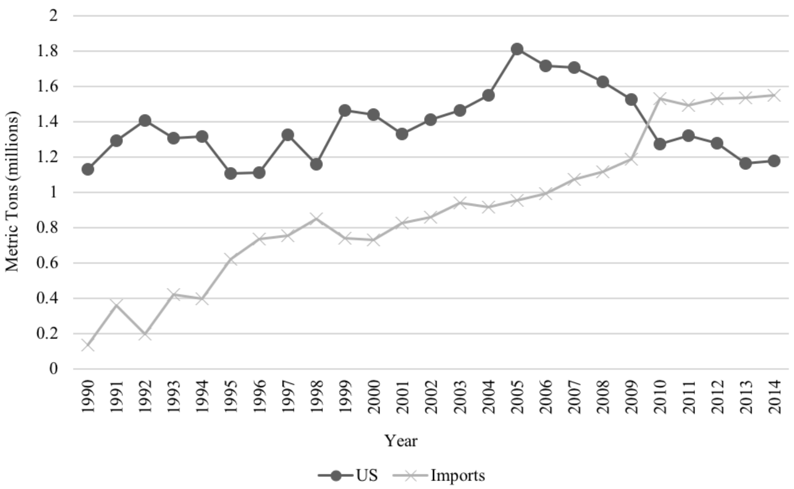

Figure 3. U.S. Fresh Tomato Production Volume versus Import Volumes, 1990–2014

Sources: U.S. Department of Commerce (2014), Thornsbury and Bond (2015).

In 2010, the market share of imported tomatoes exceeded domestic production for the first time. This trend continued into 2014, with imports accounting for a larger share of the U.S. market.

Historically, tomato trade with the United States has been contentious. In 1978, three producer groups from Florida filed an anti-dumping case against Mexican winter-produced vegetables with the U.S Department of Commerce, but the charge could not be supported and the case was dropped (Bredahl, Schmitz, and Hillman, 1987). In 1996, Florida producers filed another complaint with the U.S. International Trade Commission (USITC), claiming that Mexican tomatoes were a threat to the domestic industry. The USITC found that Mexican tomatoes could cause material injury to domestic production and proposed implementing anti-dumping tariffs (U.S. International Trade Commission, 1996).

In December 1996, Mexican producers and the U.S. Department of Commerce reached an agreement to suspend the ongoing USITC anti-dumping investigation. Mexican producers

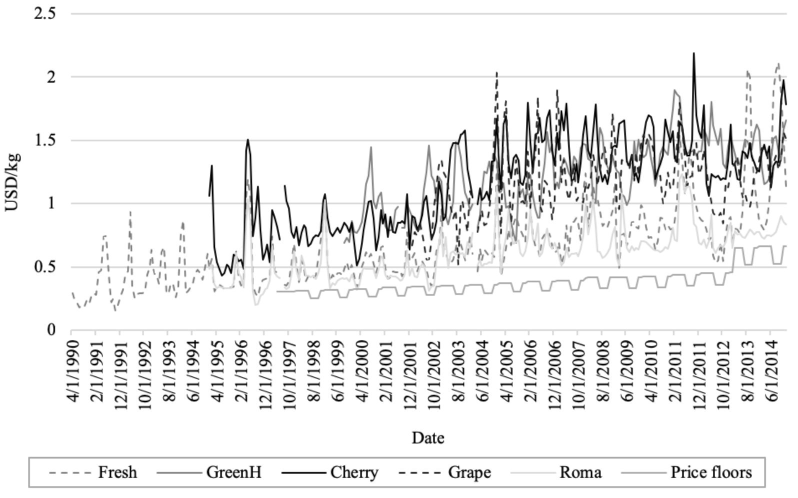

Figure 4. Monthly Mexican Tomato Prices in the U.S. Market and Price Floors, 1990–2014 (in real 2017 U.S. dollars/kg)

Sources: U.S. Department of Commerce (2014), Thornsbury and Bond (2015).

voluntarily agreed to reduce production levels and also agreed to a minimum reference price (price floor) of $0.4647/kg, which went into effect in May 1997 (U.S. Department of Commerce, 1997). In 1998, the parties reached a new suspension agreement as new regions in Mexico began producing tomatoes during the summer (July–October). This resulted in two new price floors: $0.4647/kg in the winter (November–June) and $0.3792/kg in the summer. In 2002, some Mexican producers refused to comply with the volume restrictions imposed by the suspension agreement, nearly causing a new anti-dumping investigation. In December 2002, another suspension agreement was reached, which ended the conflict (Baylis and Perloff, 2010). In 2008, the agreement was updated with a higher winter price floor of $0.4782/kg (Thornsbury, 2012).

In March 2013, a new agreement was reached in which price floors were separated by both production method and season: $0.6834/kg (winter) and $0.5418/kg (summer) for tomatoes produced in open fields or adapted environments (such as shaded areas) and $0.9038/kg (winter) and $0.7167/kg (summer) for controlled (greenhouse) production. Price floors were also implemented for specialty variety packaged ($1.3007/kg [winter] and $1.0315/kg [summer]) and loose tomatoes ($0.9921/kg [winter] and $0.7866/kg [summer]) (U.S. Department of Commerce, 2013). Interestingly, at least at monthly aggregate levels, the reference prices for Mexican tomatoes did not seem to reach lower bounds for the 1990–2014 period compared to monthly import data on prices by country of origin (U.S. Department of Commerce, 2014). At monthly aggregation levels (in 2017 U.S. dollars), actual prices remained above the price floors in the U.S. market for all varieties of fresh, greenhouse produced, cherry, grape, and Roma tomatoes (Figure 4). Even during Summer 2002, when Roma and fresh tomatoes were priced below $0.50/kg, prices were still above the $0.37/kg price floor. Other varieties have historically reached higher prices than both fresh and Roma tomatoes.

Another possible explanation for many of the issues involving the U.S.–Mexico tomato trade is exchange-rate fluctuations between the U.S. dollar and the Mexican peso and between U.S. and Canadian dollars. The nominal exchange rate for these countries' currencies varies with respect to the U.S. dollar (Figure 5). While the U.S.–Canadian dollar exchange rate has historically fluctuated within a certain range, the value of the Mexican peso has declined relative to the U.S. dollar since 1995. In real terms, Mexican tomatoes have become cheaper and cheaper, which could increase U.S. import volumes from Mexico as the U.S. domestic market demands more Mexican tomatoes at lower prices.

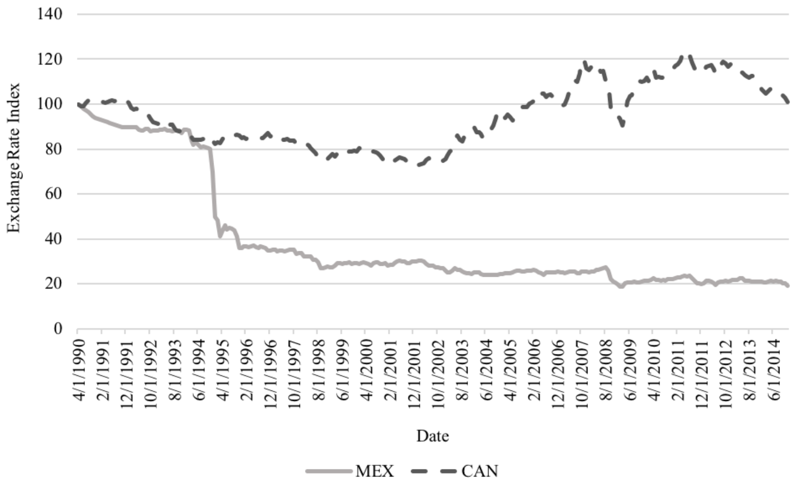

Figure 5. Nominal Exchange-Rate Index for Mexico and Canada with Respect to United States
Source: U.S. Department of Agriculture (2016).

Understanding the U.S. fresh tomato market requires quantifying the effect of exchange-rate fluctuations on import demand. Brown and Lee (2002) describe how including preference variables in a differential demand system has "adjusted" price effects on demand. These "adjusted" changes represent the combined effect of commodity prices and exchange-rate fluctuations. This study estimates a demand system that accounts for the additional effect of exchange-rate fluctuations on demand for fresh tomatoes in the U.S. market. We adapt Brown and Lee (2002) and extend preliminary work by Acharya and Schmitz (2004) to develop a model that can account for multiple exchange rates in a demand system. Incorporating multiple exchange rates allows us to realistically model their role in domestic food markets served by multiple countries. The methods we develop adhere strictly to utility theory and result in an estimable differential demand system.

Exchange-Rate Pass-Through into Import Prices

In an elegant theoretical model of a world without imperfections, exchange-rate changes would seamlessly and instantaneously pass through to commodity prices. There are many reasons to be skeptical that this occurs in the real world. In the context of North American tomatoes, the speed with which fluctuating exchange rates are passed through to U.S. tomato imports can be important. The degree to which changes in exchange rates pass through to a particular importer is an empirical question.

An approach pioneered by Campa and Goldberg (2005) addresses short- and long-run exchange-rate pass-through questions. Using their notation and following their presentation closely, we begin with the foundations of their modeling approach. At time t, import prices for country j, $P_t^{m,j}$, are linked to the export prices of a second country, $P_t^{x,j}$, though the exchange rate, E_t^j. The precise relationship is

$$P_t^{m,j} = E_t^j P_t^{x,j}. \tag{1}$$

In Campa and Goldberg's framework, export prices are marked up by $mkup_t^x$ over exporter marginal costs, mc_t^x. Making use of this relationship for a particular pair of countries j and taking the log of equation (1) yields

$$\ln(P_t^m) = \ln(E_t) + \ln(mkup_t^x) + \ln(mc_t^x). \tag{2}$$

Markups specific to individual industries and to the current macroeconomic situation can have both industry-specific fixed effects and components that are sensitive to macroeconomic conditions. Expressing the markup solely as a function of exchange rates yields

$$\ln(mkup_t^x) = \phi + \Phi \ln(E_t), \tag{3}$$

which shows that exporter marginal costs rise with rising export market wages, w_t^x, and destination market demand conditions, y_t (where y_t is a measure of economic conditions in the destination market such as gross domestic product [GDP] of the importing country):

$$\ln(mc_t^x) = c_0 \ln(y_t) + c_1 \ln(w_t^x). \tag{4}$$

Combining equations (3) and (4) and inserting the into equation (2) using logged import prices results in

$$\ln(P_t^m) = \phi + (1+\Phi)\ln(E_t) + c_0 \ln(\boldsymbol{y_t}) + c_1 \ln(w_t^x), \tag{5}$$

where $1 + \Phi = \beta$.

This modeling approach is consistent with literature explaining cross-sectional differences on exchange-rate pass-through (Dornbusch, 1987; Marston, 1990; Knetter, 1993; Yang, 1997). The degree of exchange-rate pass-through, β, depends on the structure of competition in the industry. Under the Campa and Goldberg (2005) framework, we estimate equation (5) using a log-linear regression specification:

$$\ln(p_t) = \alpha + \beta \ln(e_t) + \delta \ln(w_t) + \phi \ln(y_t) + \varepsilon_t, \tag{6}$$

where p_t are local currency import prices, e_t is the exchange rate, w_t is a primary "control" variable representing exporter costs, and $\boldsymbol{y_t}$ is a vector of other control variables including the destination market's real GDP.

Given that exact data for w_t are not readily available, to capture the shifting relative costs of a country's aggregated trading partners, we construct a consolidated export partner's cost proxy, w_t^j, for each exporting country j using both real (*reu*) and nominal (*neu*) exchange rates and computing $w_t^j = neu_t^j \left(\frac{P_t^j}{reu_t^j}\right)$. This gives a measure of trading partner costs (the exporting country costs), with each partner weighted by its importance to the importing country's trade.

Empirically, Campa and Goldberg (2005) express equation (6) in first differences. The inclusion of four lags for exchange rate and foreign production cost terms allows for the long run to be interpreted as four quarters. This allows for the possibility of gradual adjustment of import prices to exchange rates. Rewriting equation (6) in first differences and including the four lags for exchange rate and foreign production cost terms yields

$$\Delta \ln(p_t^j) = \alpha + \sum_{i=0}^{4} a_i^j \Delta \ln(e_{t-i}^j) + \sum_{i=0}^{4} b_i^j \Delta \ln(w_{t-i}^j) + c^j \Delta \ln(GDP_t^j) + \vartheta_t^j. \tag{7}$$

Under the Campa and Goldberg framework, the short-run relationship between exchange rates and country j's import prices is given by the estimated coefficient a_0^j; long-run elasticity is given by the sum of the coefficients on the contemporaneous exchange rate and four lags of exchange-rate terms, $\sum_{i=0}^{4} a_i^j$. Model parameters can be estimated with ordinary least squares using data for quarterly nominal exchange rates between the Mexican peso and the U.S. dollar, consumer price indices for the United States and Mexico (used to calculate real quarterly exchange rates), and real quarterly GDP for the United States from the Federal Reserve Bank of St. Louis, (2018b; 2018a; 2018c). We obtained monthly quantities and values of U.S. fresh tomato imports from Mexico (in U.S. dollars) for 1990–2014 from the U.S. Department of Commerce (2014). We calculated quarterly tomato prices by aggregating monthly values and dividing by aggregate monthly quantities.

Table 1. Exchange-Rate Pass-Through Results for Mexican Tomatoes in the U.S. Market

Coefficient	Parameter Estimate	Coefficient	Parameter Estimate
a_0^{Mex}	-0.212^{**}	b_0^{Mex}	0.842^{***}
	(0.093)		(0.023)
a_1^{Mex}	-0.121	b_1^{Mex}	-0.172^{***}
	(0.120)		(0.023)
a_2^{Mex}	-0.125	b_2^{Mex}	-0.197^{***}
	(0.116)		(0.022)
a_3^{Mex}	0.081	b_3^{Mex}	-0.133^{***}
	(0.120)		(0.023)
a_4^{Mex}	-0.043	b_4^{Mex}	-0.110^{***}
	(0.091)		(0.024)
$\sum_{i=0}^{4} a_i^j$	-0.420^{***}	$c^{U.S.}$	0.790^{***}
	(0.062)		(0.023)
		Constant (α)	-8.575^{***}
			(0.261)

Notes: Double and triple asterisks (**, ***) indicate statistical significance at the 5% and 1% level, respectively.

Applying equation (7) to these data yields the parameter estimates provided in Table 1. In the case of Mexican tomato import prices in the United States, there is a low short-run pass-through elasticity into import prices (one quarter) of -21%, with a standard error of 0.093, while the long-run pass-through elasticity (four quarters) is -42%, with a standard error of 0.031. These results are similar to those found by Campa and Goldberg (2005), who found the degree of exchange-rate pass-through to be significant for aggregated import prices of goods in the United States. It therefore makes sense that exchange rates may have an effect on tomato imports.

The subsequent empirical demand system estimation accounts for incomplete pass-through of exchange rates with respect to changes in the U.S. dollar. The particular form of the demand system derived below shares certain common properties with the Campa and Goldberg (2005) framework. Both models are based on first-logged differences of the variables. The evidence in Table 1 suggests that the long-run exchange-rate elasticity is more significant than the short-run elasticity. Therefore, our empirical estimation of the demand system incorporates a 1-year lag in exchange rates. Furthermore, an augmented Dickey–Fuller test, as suggested by Harvey (1990), of the logged exchange rates between Mexico and the United States could only reject nonstationarity at the 10% level of significance after including lagged variables.

Demand Theory

Many research efforts have been based on the application of demand systems, but few studies based on differential demand systems provide extensions to account for additional factors beyond prices that could affect demand. Schmitz and Seale (2002) examined Japanese fresh produce consumption, focusing on the application of a general model to determine the appropriateness of specifications such as the Rotterdam model, the Central Bureau of Statistics (CBS) model, the almost ideal demand system (AIDS), and the Natural Bureau of Research (NBR) model. Looking at U.S. fresh tomato consumption, Jung, VanSickle, and Seale (2005) tested a differential demand system, the AIDS, and double-log models to estimate import demand as a function of country of origin. Similar applications can be found in Grant, Lambert, and Foster (2010); Seale, Zhang, and Traboulsi (2013); and Asci et al. (2016), who extended the demand system to account for monthly data that could control for seasonality effects present in fresh produce data. While these efforts have provided evidence for the appropriateness of applying demand systems, they did not incorporate exchange rates into the analyses. By omitting other determinants that may have an effect on demand, such as exchange rates, the remaining estimated parameters could be biased. It is possible that the price parameters themselves could be confounded by specification errors or omitted variables.

Some researchers have suggested that exchange-rate effects may be confounded within the import price effects themselves (Dornbusch, 1987; Froot and Klemperer, 1989; Goldberg and Knetter, 1997). Brown and Lee (2002) found evidence for the presence of confounded effects when looking at women's labor participation and demand for fresh fruit. Following this notion, Acharya and Schmitz (2004) found evidence that exchange rates have an effect on demand. Looking at the demand for imported apples in several countries, Acharya and Schmitz attempted to estimate the effect of only one exchange rate in a differential demand system, with limited success. Our model builds on similar work by Valdez-Lafarga and Schmitz (2016) to extend the application of a demand system to account for the simultaneous effects of multiple exchange rates within a single system, avoiding the need to estimate separate systems for each individual exchange rate.

Econometric Model

Following Theil's (1965) differential demand system and the modifications proposed by Brown and Lee (2002), the differential demand system proposed here begins by solving the following utility maximization problem:

$$\begin{aligned} &\text{Maximize } u = u(\boldsymbol{q}, \boldsymbol{z}) \\ &\text{Subject to } \boldsymbol{p}'\boldsymbol{q} = m, \end{aligned} \tag{8}$$

where u is a utility function with the usual properties, $\boldsymbol{p}$ and $\boldsymbol{q}$ are price and quantity vectors, and m represents total expenditure. The vector $\boldsymbol{z}$ represents a set of preference variables that affect the utility function along with prices and income. Obtaining the first-order conditions for this utility maximization problem and applying total differentiation allows us to obtain the following demand functions:

$$\begin{aligned} \boldsymbol{U}\boldsymbol{dq} - \boldsymbol{p}d\lambda &= \lambda \boldsymbol{dp} - \boldsymbol{V}\boldsymbol{dz}; \\ \boldsymbol{p}'\boldsymbol{dq} &= dm - \boldsymbol{q}'\boldsymbol{dp}. \end{aligned} \tag{9}$$

where $\boldsymbol{U} = [\partial^2 \boldsymbol{u}/\partial \boldsymbol{q_i} \partial \boldsymbol{q_j}]$ and $\boldsymbol{V} = [\partial^2 \boldsymbol{u}/\partial \boldsymbol{q_i} \partial \boldsymbol{z_k}]$. $\boldsymbol{U}$ is the Hessian matrix, and $\boldsymbol{V}$ is a matrix indicating how preference variable z_k affects marginal utilities. Using Barten's fundamental matrix, it is possible to solve equation (9) and obtain the income-compensated demand equations:

$$\boldsymbol{dq} = \partial \boldsymbol{q}/\partial \boldsymbol{m}(dm - \boldsymbol{q}'\boldsymbol{dp}) + \boldsymbol{S}(\boldsymbol{dp} - \boldsymbol{V}\boldsymbol{dz}/\lambda), \tag{10}$$

where $\partial \boldsymbol{q}/\partial \boldsymbol{m} = \boldsymbol{U}^{-1}\boldsymbol{p}/\boldsymbol{p}\boldsymbol{U}^{-1}\boldsymbol{p}$, $\partial \lambda/\partial m = 1/\boldsymbol{p}\boldsymbol{U}^{-1}\boldsymbol{p}$, and

$$\boldsymbol{S} = \lambda \boldsymbol{U}^{-1} - (\partial \boldsymbol{q}/\partial \boldsymbol{m})(\partial \boldsymbol{q}/\partial \boldsymbol{m})'(\lambda/(\partial \lambda/\partial m)). \tag{11}$$

where the changes in quantity demanded with respect to the preference variables can be obtained from $\partial \boldsymbol{q}/\partial \boldsymbol{z}' = -\boldsymbol{S}\boldsymbol{V}/\lambda$.

We estimate the following differential demand system by extending Brown and Lee (2002) to include multiple preference variables:

$$w_i d\ln q_i = \theta_i d\ln Q + \sum_j \pi_{ij} d\ln p_j + \sum_k \beta_{ik} d\ln z_k,\ i = 1, 2, \ldots, n \text{ and } k = 1, 2, \ldots, r, \tag{12}$$

where n is the number of countries from which tomatoes are demanded by U.S. consumers; r is the number of exchange rates; $w_i = p_i q_i / m$ is the budget share for good i; $\theta_i = p_i(\partial q_i / \partial m)$ is the marginal budget share; $d\ln Q = \sum w_i d\ln q_i$ is the Divisia volume index; $\pi_{ij} = (p_i p_j / m)s_{ij}$ is the (i, j)th Slutsky coefficient; $s_{ij} = ((\partial q_i / \partial p_j) + (q_j \partial q_i / \partial m))$ is the (i, j)th element of the substitution matrix $\boldsymbol{S}$; and $\beta_{ik} = w_i(\partial \ln q_i / \partial z_k)$ is the (i,k)th exchange-rate coefficient, which indicates how the demand for the ith good is affected by the exchange rate between the U.S. and the kth country. The theoretical restrictions for this system of demand equations can be written as (Brown and Lee, 2002)

$$\text{Adding up: } \sum_i \theta_i = 1,\ \sum_i \pi_{ij} = 0,\ \sum_i \beta_{ik} = 0; \tag{13}$$

$$\text{Homogeneity: } \sum_j \pi_{ij} = 0; \tag{14}$$

$$\text{Symmetry: } \pi_{ij} = \pi_{ji}. \tag{15}$$

Coefficients θ_i and π_{ij} are considered constants in the standard absolute version of the Rotterdam model. However, it may not be appropriate to treat β_{ik} as constants, since $\partial \boldsymbol{q} / \partial \boldsymbol{z}' = -\boldsymbol{SV}/\lambda$. Resulting estimates may not satisfy the restrictions on demand described by equations (13)–(15). Instead, we employ the following specification:

$$\beta_{ik} = \sum_j -\pi_{ij}\gamma_{jk},\ i = 1, 2,\ \ldots, n \textbf{ and } k = 1, 2,\ \ldots,\ r, \tag{16}$$

where $\gamma_{jk} = \partial \ln(\partial u / \partial q_j) / \partial \ln z_k$ is the elasticity of the marginal utility of good j with respect to preference variable z_k. Adding-up and other restrictions can be imposed on γ_{jk} instead of β_{ik}. Therefore, equation (12) can be estimated directly by eliminating the nth equation and performing an iterative seemingly unrelated regression on the system:

$$\begin{gathered} w_i d\ln q_i = \theta_i d\ln Q + \sum_j \pi_{ij}[d\ln p_j - d\ln p_n - \sum_k \gamma^n_{jk} d\ln z_k], \\ i = 1, \ldots,\ n-1, \text{ and } k = 1, 2,\ \ldots,\ r. \end{gathered} \tag{17}$$

where $\gamma^n_{jk} = \gamma_{jk} - \gamma_{nk},\ j = 1,\ \ldots,\ n-1$. System (17) can be viewed as a relative version of the differential demand system modified to account for the effect of exchange rates, while equation (12) can be viewed as an absolute version of the same system also modified to account for the effects of exchange rates.

Actual estimation of system (17) yields a reduced form for the coefficients β_{jk} associated with $d\ln z_k$. Individual γ_{jk} parameters cannot be identified from system (17). Instead, a linear combination of the coefficients is recoverable from β_{jk} through the relationship

$$(\boldsymbol{\gamma}^*_{\boldsymbol{k}} - \boldsymbol{\iota}\gamma_{nk}) = -\boldsymbol{\pi}^{*-1}\boldsymbol{\beta}^*_{\boldsymbol{k}},\ k = 1,\ \ldots,\ r, \tag{18}$$

where $\boldsymbol{\gamma}^*_{\boldsymbol{k}} = (\gamma_{1,k} \ldots \gamma_{n-1,k})'$, $\boldsymbol{\pi}^* = [\boldsymbol{\pi_{ij}}]$, $\boldsymbol{\beta}^*_{\boldsymbol{k}} = (\beta_{1,k} \ldots \beta_{n-1,k})'$, $\boldsymbol{\iota}$ is the summation vector, and $[\boldsymbol{\pi_{ij}}]$ is the $(n-1 \times n-1)$ matrix containing the first $n-1$ Slutzky coefficients.

To estimate θ_i and π_{ij} in the differential demand system described above, it was necessary to drop one of the equations. Barten (1969) suggests that an arbitrary equation be dropped given that the system is singular. Therefore, we estimated the system for n-1 equations through iterative seemingly unrelated regression (SUR) using a procedure in the STATA statistical software. We restricted all constants to 0 to satisfy the adding-up condition from demand theory and imposed homogeneity and Slutsky symmetry during estimation. Estimates of γ^n_{ik} were obtained directly from β_{ik} and π_{ij} through matrix multiplication based on relationship (18). The variances of γ^n_{ik} were estimated using a series of STATA nlcom function calls involving nonlinear combinations of β_{ik} and a macro for the general inverse of the 3×3 matrix ($\boldsymbol{\pi}^*$). The standard errors of ${\gamma_{ik}}^n$ were calculated by taking the square root of the corresponding variances.

The elasticities and associated standard errors were calculated from the parameter estimates using the following relationships:

(19) $$\eta_i = \theta_i / w_i;$$

(20) $$S_{ij} = \pi_{ij} / w_i;$$

(21) $$E_{ik} = \beta_{ik} / w_i.$$

The elasticities are calculated at the sample mean budget share. Relationship (19) represents the conditional expenditure elasticity for each good i, which indicates consumers' propensity to purchase the good. If $\eta_i > 1$, then a 1% increase in expenditure on tomatoes causes a >1% increase in consumption of good i. However, if $\eta_i < 1$, then a 1% increase in expenditures on tomatoes causes a <1% increase in consumption of good i. Relationship (20) represents the conditional compensated Slutsky price elasticities for each of the goods with respect to themselves and other goods. These measures indicate the percentage response in quantities demanded from a 1% change in price (holding real expenditures constant). Above 1, the good is price elastic; below 1, the good is price inelastic. For the case of Slutsky price elasticities of a good with respect to the prices of other goods (when $i \neq j$), a positive sign indicates that the two products are substitutes. On the other hand, a negative sign indicates that the products are complements. Relationship (21) represents the conditional compensated exchange-rate elasticities for each good. If $E_{ij} < 0$, then appreciation of the foreign currency with respect to the U.S. dollar causes U.S. demand for tomatoes from country i to decrease.

Data

Monthly fresh tomato imports by country of origin and value (in U.S. dollars) were obtained for 1990–2014 from the U.S. Department of Commerce, U.S. Imports of Merchandise database (2014). The database consists of monthly records of the amount, value, and origin for all merchandise imported by the United States. These records are available as monthly compact discs. The original records are in Dbase III format (.dbf) for 1990–2008, and in text format (.txt) for 2009–2014. Data correspondence was maintained by matching field definitions across formats.[1]

This study focuses on imports of tomatoes to the U.S. market from countries participating in the North American Free Trade Agreement (NAFTA). Mexico and Canada (which account for the largest share of imports) are the only disaggregated countries analyzed individually, while tomatoes from other countries were aggregated into a rest of the world (ROW) group. Domestic tomato production and prices for 1990–2010 were obtained from U.S. Department of Agriculture (2014) Economic Research Service shipping-point reports. Data after 2010 were obtained from daily U.S. Department of Agriculture (2015) Agricultural Marketing Service shipping-point reports. We aggregate all tomato varieties into monthly observations by country of origin, similar to Asci et al. (2016). Data for nominal U.S.–Mexico and U.S.–Canada exchange rates for 1990–2014 were obtained from the Economic Research Service (U.S. Department of Agriculture, 2016).

Results

First, we conduct a standard differential demand system (Rotterdam model without exchange rates) to test the adherence of these data to the theoretical restrictions for demand equations. This model serves as a base to test the appropriateness of including exchange rates to explain demand for fresh

[1] Since 1990, the United States has imported tomatoes from Argentina, the Bahamas, Belgium, Botswana, Brazil, Canada, Chile, Colombia, Costa Rica, Denmark, the Dominican Republic, Ecuador, France, the Gaza Strip, Germany, Guatemala, India, Israel, Italy, Luxemburg, Mauritius, Mexico, Morocco, Mozambique, the Netherlands, New Zealand, Niger, Norway, Poland, Somalia, Spain, Sweden, Switzerland, Thailand, Trinidad and Tobago, the United Kingdom, and Venezuela.

Table 2. Rotterdam Model without Exchange Rates: Conditional Parameter Estimates for U.S. Demand for Fresh Tomatoes from Selected Countries, 1991–2014

Parameters	Price (π_{ij})				Marginal
Country	Mexico	Canada	U.S.	ROW	Shares (θ_i)
Mexico	-0.091^{***}	0.005	0.084^{***}	0.002	0.372^{***}
	(0.012)	(0.004)	(0.018)	(0.002)	(0.048)
Canada		-0.019^{***}	0.011^{***}	0.004	0.036^{***}
		(0.005)	(0.003)	(0.002)	(0.009)
U.S.			-0.101^{***}	0.006^{***}	0.579^{***}
			(0.012)	(0.002)	(0.048)
ROW				-0.011^{***}	0.014^{**}
				(0.002)	(0.006)

Notes: Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level, respectively.

tomatoes in the U.S. market. Tomatoes from each country are treated as separable from other goods. Therefore, the demand system is conditional on expenditure allocated to tomatoes from the countries studied. On the basis of the theory of rational random behavior, we treat the Divisia volume index as independent from the error term in each equation for the tomatoes from a given country (Theil, 1975, 1976, 1980; Brown, Behr, and Lee, 1994; Brown and Lee, 2002). We estimated the model by dropping the ROW equation and obtaining its parameters from the adding-up restrictions (13).

Table 2 presents parameter estimates of the base model without exchange rates. Domestic tomatoes account for the largest marginal budget share, while Mexico accounts for the second largest. All expenditure shares are statistically significant (at the 5% and 1% level). All Slutsky own-price parameters are negative (and significant at the 1% level), in accordance with demand theory. All cross-price parameters are positive, as expected, and all cross-price effects between domestic tomatoes and imported tomatoes are significant (at the 1% level), which supports the hypothesis that there is significant differentiation between domestic tomatoes and foreign tomatoes.

To test homogeneity and symmetry in the Rotterdam model (without exchange rates), we conduct a log-likelihood ratio test. The number of restrictions for a model with homogeneity and symmetry imposed is

$$q = (c-1) + \left(\frac{(c-1)(c-2)}{2}\right), \tag{22}$$

where c represents the number of countries analyzed in the model (four in this case); therefore, the value of q is 6, which gives a critical value of 12.59 for a 5% significance level and a critical value of 16.81 for a 1% significance level. With a test-statistic value of 16.02, there is evidence at the 5% level that homogeneity and symmetry cannot be rejected.

Table 3 reports the Slutsky (compensated) price elasticities of demand. Mexican and domestic tomatoes are expenditure elastic, and Canadian and ROW tomatoes are expenditure inelastic. Therefore, increased expenditures on tomatoes would cause disproportionately more consumption of domestic and Mexican tomatoes than of Canadian and ROW tomatoes. Both imported and domestic tomatoes are own-price inelastic. In addition, domestically produced tomatoes are substitutes with respect to ROW tomatoes, which is to be expected.

Without accounting for exchange rates, the general result is that, while demand for fresh tomatoes in the U.S. market is not price elastic, it is income (expenditure) elastic, with tomatoes from the U.S. and Mexico disproportionately benefiting from increased U.S. consumer expenditures in these commodities. The results are similar to those obtained by Asci et al. (2016), except that tomatoes from the United States, Canada, and Mexico are more inelastic (have less negative

Table 3. Conditional Expenditure and Slutsky (Compensated) Price Elasticity Estimates for U.S. Demand for Fresh Tomatoes from Selected Countries, 1991–2014 (Rotterdam model without exchange rates)

Country	Expenditure Elasticities	Own-Price Elasticities	Cross-Price Elasticities: Mexico	Canada	U.S.	ROW
Mexico	1.071***	−0.263***	–	0.014	0.242***	0.006
	(0.137)	(0.035)		(0.010)	(0.034)	(0.006)
Canada	0.478***	−0.259***	0.065	–	0.145***	0.049
	(0.120)	(0.063)	(0.048)		(0.034)	(0.030)
U.S.	1.039***	−0.181***	0.151***	0.019**	–	0.010***
	(0.087)	(0.022)	(0.021)	(0.005)		(0.003)
ROW	0.633**	−0.540***	0.105	0.169	0.265***	–
	(0.261)	(0.082)	(0.093)	(0.104)	(0.070)	

Notes: Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level, respectively.

estimates). Differences in the magnitudes of the price elasticities can be attributed to differences in the level of aggregation and the fact that Asci et al. (2016) report estimates for more general variants of the differential demand system.

In our efforts to account for the effect of exchange rates on the demand for fresh tomatoes, we estimate two different versions of the modified differential demand system: An absolute version of the model described by equation system (12) and a relative version of the model described by equation system (17). As in the case of our base model without exchange rates, models (12) and (17) treat tomatoes from each country as separable goods and treat the Divisia volume index as independent from the error term in each of the country's tomato demand equation. However, these models also account for the effect of exchange rates (U.S. dollars–Mexican pesos and U.S.–Canadian dollars), which are introduced using vector $\boldsymbol{z}$ as described in equation systems (12) and (17).

To test the inclusion of the exchange-rate variables in the model, we conduct a log-likelihood ratio test. The null hypothesis of this test is that exchange rates do not improve the model fit. The test statistic is equal to twice the difference between the log-likelihood values of the restricted (homogeneity- and symmetry-imposed) model without exchange rates, and the model with exchange rates (also with homogeneity and symmetry imposed). This test statistic is asymptotically distributed as a χ^2 statistic with degrees of freedom equal to the number of restrictions, which in this case is equal to the number of γ_{ik}^{n} parameters.

In our case, six γ_{ik}^{n} parameters were introduced into the unrestricted model, since γ_{ik}^{n} are constructed as differences with respect to the elasticity of marginal utility with respect to each exchange rate for ROW tomatoes (γ_{nk}). The restricted model is associated with a critical value of 12.59 at the 5% level. With a test statistic equal to 70.72 for the unrestricted model, the test rejects the exclusion of the exchange-rate parameters at the 5% level. Therefore, there is evidence to suggest including the exchange rates in the model. Under the assumptions of homogeneity and symmetry, both systems with exchange rates included produce the same parameter estimates (Table 4).

Comparing the parameters results from Table 4 with those reported in Table 2, we find that, when compared to the differential demand system with no exchange rates, the marginal budget shares, θ_i, remain largely similar. Domestic tomatoes hold the largest marginal budget shares, followed by imports from Mexico, Canada, and the rest of the world, in that order. As expected, all Slutsky own-price parameters are negative (and statistically significant), while cross-price parameters are positive, as expected. The reduced form coefficients, β_{MX}, for the Mexican peso–U.S. dollar exchange rate are all statistically significant. These coefficients are negative for tomatoes from other countries and positive for U.S. domestic tomatoes. Therefore, an appreciation of the Mexican peso with

Table 4. Differential Demand Parameter Estimates of U.S. Demand for Fresh Tomatoes from Selected Countries, 1990–2014 (including exchange rates, demand systems 12 and 17)

Panel A. Price Parameters and Marginal Share Parameters

	Price (π_{ij})				Marginal
Country	**Mexico**	**Canada**	**U.S.**	**ROW**	**Share (θ_i)**
Mexico	−0.089***	0.005	−0.081***	0.003	0.337***
	(0.012)	(0.003)	(0.011)	(0.002)	(0.047)
Canada		−0.019***	−0.010***	0.003	0.030***
		(0.005)	(0.002)	(0.002)	(0.009)
U.S.			−0.098***	0.007***	0.617***
			(0.011)	(0.001)	(0.046)
ROW				−0.014**	0.016**
				(0.002)	(0.005)

Panel B. Exchange-Rate Parameters

Country	β_{MX}	β_{CAN}	γ_{MX}	γ_{CAN}
Mexico	−0.165**	0.087	−0.021	−3.17**
	(0.034)	(0.074)	(0.533)	(0.987)
Canada	−0.027***	0.018	−0.392	−3.07**
	(0.006)	(0.014)	(0.551)	(0.998)
U.S.	0.207***	−0.068	2.034**	2.22**
	(0.034)	(0.078)	(0.407)	(0.407)
ROW	−0.014**	−0.037**		
	(0.004)	(0.998)		

Notes: Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level, respectively.

respect to the U.S. dollar has a negative effect on tomato imports and a positive effect on U.S. domestic tomatoes. For the Canadian–U.S. dollar exchange rate, the reduced form β_{CAN} coefficients are statistically significant only for ROW tomatoes. The coefficient for this case was also negative, meaning that ROW tomatoes are negatively affected by an appreciation of the Canadian dollar with respect to the U.S. dollar.

Table 4 also reports estimates for the structural coefficients, γ_{ik}^{n}, which provide measures of how each exchange rate affects the marginal utility of tomatoes from different countries. Columns γ_{MX} and γ_{CAN} provide the estimates obtained from model (17). Each estimate for tomatoes from a given country represents that commodity's elasticity of marginal utility with respect to a given exchange rate less the elasticity of marginal utility with respect to that same exchange rate, with respect to ROW tomatoes. The estimates suggest that the elasticity of marginal utility with respect to the Mexican peso–U.S. dollar exchange rate for U.S. domestic tomatoes was significantly higher than the elasticity for ROW tomatoes. The elasticity of marginal utility with respect to the Mexican peso–U.S. dollar exchange rate for tomatoes from other countries was not statistically different from the elasticity for ROW tomatoes. The elasticities of the marginal utility with respect to the Canadian–U.S. dollar exchange rate were significantly higher for all countries compared to the elasticity for ROW tomatoes.

Table 5 presents the Slutsky (compensated) elasticities associated with models (12) and (17). Domestic tomatoes are expenditure elastic, while imported tomatoes are expenditure inelastic. If

Table 5. Conditional Expenditure and Slutsky (Compensated) Price Elasticity Estimates for U.S. Demand for Fresh Tomatoes from Selected Countries, 1991–2014 (including exchange rates, demand systems 12 and 17)

Country	Expenditure Elasticities	Own-Price Elasticities	Cross-Price Elasticities: Mexico	Canada	U.S.	ROW
Mexico	0.972**	−0.257**	–	0.015	0.233**	0.008
	(0.138)	(0.035)		(0.010)	(0.033)	(0.005)
Canada	0.397**	−0.248**	0.069	–	0.135**	0.042
	(0.119)	(0.062)	(0.047)		(0.033)	(0.023)
U.S.	1.107**	−0.177**	0.145**	0.018**	–	0.013**
	(0.084)	(0.021)	(0.021)	(0.004)		(0.002)
ROW	0.750**	−0.643**	0.141	0.146	0.354**	–
	(0.249)	(0.081)	(0.088)	(0.103)	(0.067)	

Notes: Double asterisks (**) indicate statistical significance at the 5% level.

overall expenditures on tomatoes increase, the marginal budget share for U.S. domestic tomatoes would increase and the marginal budget share would decrease for tomatoes from all other countries. Tomatoes from all origins are own-price inelastic and are substitutes among one another, as is evident from the positive sign of the cross-price parameters. Comparing the cross-price elasticities associated with the exchange rate model with those associated with the base model reveals that domestic tomatoes are still significant substitutes for imported tomatoes. Compared to the results obtained by Asci et al. (2016), we find that the magnitude of the own-price elasticities is smaller, while Mexican tomatoes are expenditure inelastic. We also find fewer cross-price elasticities to be significant. These results suggest that the degree of substitution is larger in models that do not account for exchange-rate effects.

Table 6 reports the exchange-rate elasticities for models (12) and (17). The elasticities of demand with respect to the Mexican peso–U.S. dollar exchange rate are statistically significant (E_{MX} column). Elasticities with respect to this exchange rate are positive for U.S. domestic tomatoes and negative for ROW tomatoes, suggesting that an appreciation of the Mexican peso with respect to the U.S. dollar would result in increased consumption of U.S. domestic tomatoes and decreased consumption of imported tomatoes from all other countries. The elasticities of demand with respect to the Canadian–U.S. dollar exchange rate (E_{CAN} column) are only statistically significant for the demand for ROW tomatoes. Demand for ROW tomatoes would decrease if the Canadian dollar appreciated with respect to the U.S. dollar.

Finally, we plot actual imports of Mexican tomatoes against predicted imports using models that do and do not account for the effects of exchange rates (Figures 6 and 7). Broadly speaking, the two models mimic each other fairly closely. Of course, throughout much of the study period exchange rates were relatively stable, so there is little reason to expect much difference. The importance of exchange rates becomes clear, however, in the volatile 1993–1995 period, when the U.S. dollar rapidly appreciated against the peso. Allowing a year to pass for markets to adjust shows the practical dominance of models that explicitly model exchange-rate effects. The model without exchange rates significantly under-predicts actual imports (Figure 6). The model that includes exchange rates closely matches actual U.S. imports (Figure 7). In 1996, when exchange rates stabilized, the two models again yield similar results.

Table 6. Exchange-Rate Elasticities for U.S. Import Demand for Fresh Tomatoes from Selected Countries, 1991–2014 (demand systems 12 and 17)

Country	E_{MX}	E_{CAN}
Mexico	-0.475^{**}	0.250
	(0.098)	(0.214)
Canada	-0.372^{**}	0.238
	(0.086)	(0.186)
U.S.	0.372^{**}	-0.122
	(0.061)	(0.133)
ROW	-0.660^{**}	-1.691^{**}
	(0.182)	(0.395)

Notes: Double asterisks (**) indicate statistical significance at the 5% level.

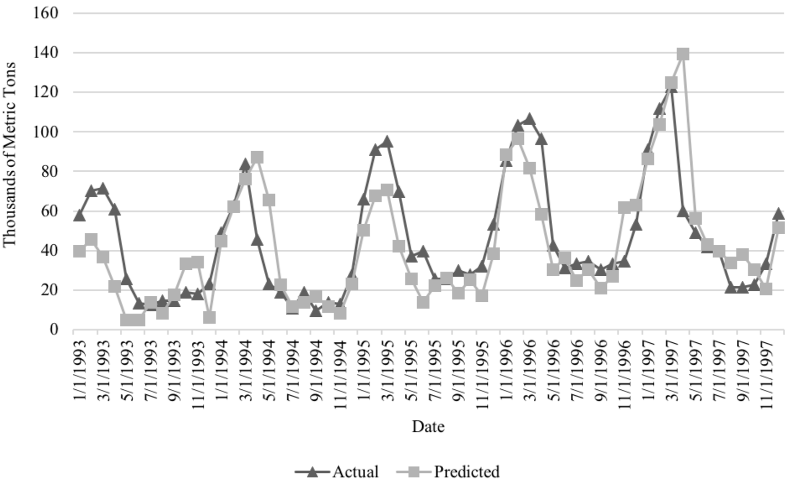

Figure 6. Predicted and Actual U.S. Imports of Mexican Tomatoes from Differential Demand Model without Accounting for Exchange-Rate Effects, 1993–1997

Source: Author's calculations.

Conclusions

In a world without imperfections, exchange-rate changes would seamlessly and instantaneously pass through to commodity prices. In reality, there are many instances in which importers experience incomplete exchange-rate pass-through. We found significant evidence of incomplete pass-through for Mexican tomatoes into the United States. We developed a modified differential demand system that allows an arbitrary number of exchange rates to affect demand. In this case, we incorporated U.S.–Mexico and U.S.–Canada exchange rates and estimated them simultaneously in a complete demand system to account for the effect of differences in exchange rates on U.S. tomato demand. Comparing these results with those obtained by Asci et al. (2016) suggests that income and price elasticities are overestimated if incomplete exchange-rate pass-through is not considered.

Comparing the results from Tables 3 and 5, the addition of exchange-rate effects caused Mexican tomatoes to switch from being expenditure elastic to being expenditure inelastic. Additionally, several cross-price elasticities are smaller, and more of them are not significant, when the demand

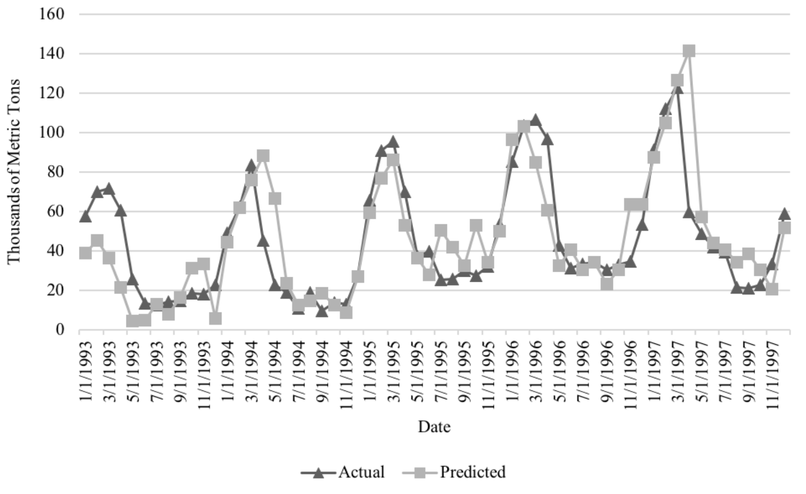

Figure 7. Predicted and Actual U.S. Imports of Mexican Tomatoes from Differential Demand Model Accounting for Exchange-Rate Effects, 1993–1997

Source: Author's calculations.

system accounts for exchange-rate effects. The statistical evidence suggests that a stronger dollar increases U.S. tomato imports from Mexico. Under current U.S. market demand conditions, Mexican producers would benefit from a strong dollar. Overall, demand for imported tomatoes in the U.S. market would increase if the U.S. dollar appreciates with respect to other currencies, as U.S. consumers could purchase more imports cheaply. On the other hand, a weakening of the U.S. dollar with respect to other currencies would result in U.S. consumers demanding more domestic tomatoes, as domestic tomatoes would become relatively less expensive.

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