Nonhomogeneous Products and the Law of One Price

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ABSTRACT

Law of One Price (LOP) is important in the theory of international trade. It is important in LOP studies to have data that accurately represents homogeneous products (i.e., the product in one country has the same product characteristics as the product in another country). We present a theoretical model that determines fresh grapefruit prices Free on Board (FOB) at the packinghouse. The first order conditions show that the FOB packinghouse prices are equal for products with the same product characteristics. The theoretical conditions show a difference in FOB prices when the product characteristics are different. The product characteristics that are varied include packing costs and pack-out rates. The results from a nonlinear programming optimization routine demonstrates the importance of using data that accurately represents homogeneous products for LOP studies. Different packing costs and pack-out percentages are shown to cause different FOB packinghouse prices for fresh grapefruit destined for domestic and export markets. [JEL Classification: Q11, Q13, F14]. © 2007 Wiley Periodicals, Inc.

1. INTRODUCTION

A significant amount of empirical research has been done on the validity of the Law of One Price (LOP) (Miljkovic, 1999). Authors have found the LOP to hold among some products and not others (Ardeni, 1989; Baffes, 1991; Zanias, 1993). Authors have questioned the modeling techniques used (Goodwin 1992a, 1992b; Goodwin, Greenes, & Wohlgenant, 1990; Mohanty, Peterson, & Smith, 1998). Some of the reasons that the LOP is not universally found among goods traded among countries include price

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discrimination among markets (pricing to market), exchange rate risk, geographical separation of markets (transportation costs, tariffs, and non-tariff barriers), institutional factors that influence prices among markets, non-tradable inputs of production, and high costs of arbitrage among markets (Miljkovic, 1999). Miljkovic concludes by saying, "Thus, a great deal of caution is necessary before making any conclusion or decision regarding the LOP in any product" (p. 137).

Tweeten (1992, p. 289) notes that data must be accurate in order for trade models to give accurate predictions. Miljkovic (1999, p. 137) agrees with Tweeten about data quality and indicates that data accuracy is an issue that cannot be ignored in studies dealing with the LOP. A basic assumption of the LOP is that the product traded among countries is homogenous; however, the data used by researchers may not support this assumption. Gehlhar and Pick (2002) found that for 372 food products, 60% of U.S. food imports and 40% of U.S. food exports could be categorized as non-price competitive (i.e., product characteristics differ from product to product), which means the product from different countries are not homogeneous. This is a clear violation of a basic assumption on which the LOP is based. This would cause a product to violate the LOP, not because it is a homogeneous product among countries that violates the LOP, but because the product is not homogeneous among countries and should violate the LOP.

For example, violation of the LOP will occur when a product, otherwise homogeneous, incurs a differential packing cost if traded domestically or internationally. An additional packing cost for international markets could include heavier boxes and chemical treatments required by the international market and not required for the domestic market. This discrepancy can occur in all commodities; however, it is especially prevalent in commodities sold fresh such as fruits and vegetables. In the case of the Florida grapefruit, the fruit sold in Europe and Japan requires more stringent packing specifications than the fruit that is packed to be sold in the U.S. market. Thus, there is a price difference that cannot be accounted for by the normal factors that cause price differences in LOP studies.

Furthermore, pack-out rate, i.e., the percentage of fruit sent to a packinghouse that is acceptable for the fresh market, can also differ among markets and cause price differences. The product going to each market has specific consumer preferences, especially with respect to fruit size and external appearance; therefore, grapefruit may appear to the uninformed to be homogeneous across markets but is not. Grapefruit in Japan and its counterpart in the European Union or the U.S. appear to be homogeneous but are not. Grapefruit are truly homogeneous if the pack-out rates among markets are equal; however, if the pack-out rates are different, the prices among the markets are found to be different because the product has different product characteristics and is therefore not homogeneous.

In this article, we show how important it is to have data that clearly shows that the product in one country has the same product characteristics as the product in another country (i.e., satisfying the assumption of a homogeneous product). First, we describe a theoretical model that determines fresh grapefruit prices Free on Board (FOB) at the packinghouse. Then we use the first order conditions to show that the FOB packinghouse prices are equal for products with the same product characteristics (i.e., the products are homogeneous). Then we show that the theoretical conditions have a difference in FOB prices when the product characteristics are different (i.e., the product is not homogeneous among countries). The product characteristics that are varied are packing costs and pack-out rates. We then use a nonlinear programming optimization routine that demonstrates the theoretical results and shows the magnitude of the FOB price differences when product characteristics are varied. Different packing costs and pack-out percentages are used to determine the impact on the FOB packinghouse prices of fresh grapefruit destined for domestic and export markets.

2. CONCEPTUAL MULTI-MARKET EQUILIBRIUM MODEL

To assess the impact of product characteristics (i.e., packing costs and pack-out rates) on FOB packinghouse prices, a multi-market equilibrium model is used. This model is similar to the Takayama and Judge (1971) spatial equilibrium model except transportation costs are not included in the model. As one reviewer pointed out, eliminating transportation costs is not the only way of measuring the impact of product characteristics on FOB prices. Instead of using inverse derived demand equations (Equation 1) at the FOB packinghouse level, inverse derived demand equations at the destination port of entry could be used. In the analysis, transportation cost must be subtracted from the price at the port of entry that would yield the FOB price at the packinghouse. The impact of product characteristics on FOB packinghouse prices would be the same with either set of inverse derived demand equations because the difference between the port of entry inverse derived demand equation and the FOB packinghouse derived demand equation would be the transportation cost. The two equations would be parallel. Subtracting the transportation cost from the port of entry inverse derived demand equations would yield the FOB packinghouse price. Thus, inverse derived demand equations at the packinghouse level were used to directly determine the impact of product characteristics on FOB prices.

The model emphasizes two commodities: white grapefruit and red grapefruit. They are distributed to fresh and processed markets, both domestic and export. The demand side of the equation has four fresh grapefruit markets and one for processed juice market. These include a domestic market for fresh white grapefruit and one for fresh red grapefruit, an export market for fresh white grapefruit and one for fresh red grapefruit, and a market for processed juice. This is the approached followed by Ali (2000). In a study by Pana (1991), a similar approach is followed; however, Pana (1991) uses an explicit specification for domestic and export juice markets. Given the relative small proportion of juice exports relative to the domestic market, our model combines both markets into a single market for processed juice. Juice from white grapefruit and red grapefruit is combined into processed juice. Red Seedless and white seedless grapefruit are sold in both domestic and export markets. The main export markets are Japan, the European Union, and Canada. The product going to each market can have different packing costs and specific consumer preferences, especially with respect to fruit size and external appearance. Therefore, to the uninformed, grapefruit may appear to be homogeneous across markets when, in fact, it varies in fruit size and external appearance, depending upon the market in which it is traded.

The supply and demand components of each market are integrated through the market equilibrium conditions. The final result is a multi-market equilibrium model specifically applied to the grapefruit industry in the Florida.

3. THEORETICAL MULTI-MARKET EQUILIBRIUM MODEL

Let the inverse derived demand in each fresh market at the output door of the packinghouse be

$$P_{vj} = \alpha_{vj} - \beta_{vj} Q_{vj}^{D} \tag{1}$$

where P_{vj} is the price per box (1 and 3/5 bushels) of variety v (red and white) and market j (domestic and export); α_{vj} and β_{vj} are positive parameters and Q_{vj}^{D} is the quantity (i.e., number of boxes) of variety v and market j.

Let the supply X_{vj} be the boxes of variety v available to market j. The quantity packed for the fresh market is

$$Q_{vj}^{D} = \lambda_{vj} X_{vj} \tag{2}$$

where X_{vj} differs from Q_{vj}^{D} because only a portion of the fruit intended for market j will meet the quality standard associated with market j. In the industry, the proportion of fruit that meets the fresh market standard is called the pack-out rate, denoted in equation (2) by λ_{vj}. The portion of fruit that does not meet the specification of the fresh market is called eliminated fruit or "eliminations." Eliminations are sent to the processing plant to be processed into juice. Let the eliminated fruit be denoted by Q_{vj}^{E} and

$$Q_{vj}^{E} = (1 - \lambda_{vj}) X_{vj}. \tag{3}$$

Because differences in eliminated fruit is mainly cosmetic and not size of the fruit, it's safe to assume that the juice content of eliminated fruit is the same regardless of whether it was intended for the domestic or export market. Let JU be the juice yield associated with one box of grapefruit. In this analysis, no attempt is made to differentiate between the juice derived from red seedless and white seedless grapefruit. Therefore juice production is given by

$$JP = \sum_{v} JU\left(\left(\sum_{j} (1 - \lambda_{vj}) X_{vj}\right) + FR_{v}\right) \tag{4}$$

where JP denotes the single strength equivalent (SSE) gallons of juice produced in a particular season; JU is gallons of juice per box (4.8 gallons) that does not vary by variety; and FR_v is the quantity of variety v that goes from the grove directly to the processing plant. The inverse derived demand equation (FOB the packinghouse) for grapefruit juice is

$$P_{J} = \alpha - \beta \cdot Q_{J} \tag{5}$$

where P_J is the price per SSE gallon and Q_J denotes the gallons consumed. If juice inventory adjustment is ignored, then in any particular season

$$JP = Q_{J}. \tag{6}$$

Define PD_v as the total boxes of variety v in a particular season. Let PC_j be the packing costs per box associated with fruit destined for market j. The absence of a subscript for variety implies that packing costs do not depend upon variety. Let PR denote processing costs expressed in dollars per SSE gallon of final product.

With these definitions and assumptions, an allocation model can be written in which the competitive allocation of fruit by variety is

$$\text{Max} \sum_{v} \sum_{j} \int (\alpha_{vj} - \beta_{vj} Q_{vj}^{D}) dQ_{vj}^{D} + \int (\alpha - \beta Q_J)\, dQ_J - \sum_{v} \sum_{j} PC_j Q_{vj}^{D} - PR \cdot Q_J \tag{7}$$

$$s.t. \quad \sum_{j} X_{vj} + FR_v \leq PD_v \qquad v = \text{red, white} \tag{8}$$

$$Q_{vj}^{D} \leq \lambda_{vj} X_{vj} \quad j = \text{domestic, export} \tag{9}$$

$$Q_J \leq \left(\sum_{v} JU \left(\left(\sum_{j} (1 - \lambda_{vj}) X_{vj} \right) + FR_v \right) \right). \tag{10}$$

All variables are non-negative.

This model is a multi-market equilibrium model; however, supply is predetermined (i.e., supply is perfectly inelastic) and there are no transportation costs. The output markets are FOB the packinghouse. The area under the derived demand functions at the equilibrium quantities is maximized in the objective function (Equation 7) for all the markets. Fruit is allocated to the fresh markets and the processed market to attain equilibrium prices based on the supply of grapefruit that is fixed in the short run. Producers are unable to respond to price change in the short run which makes the supply perfectly inelastic. The first constraint (set of Equations 8) represents the balance between supply and total derived demand. The boxes sent to the packinghouse or the processing plant (field run) for the juice market must be less than or equal to the total grapefruit production of each variety. The next four constraints (set of Equations 9) are the balancing constraints between boxes sent to the packinghouse and the boxes actually packed for fresh use. The last constraint (10) balances the juice from the boxes not qualified for the fresh market (elimination) plus the juice from the field run boxes with total consumption of juice. The model does not store juice and 4.8 gallons of juice is produced by one box of fresh grapefruit. The model determines the equilibrium prices and quantities FOB the packinghouse. The model is run taking 2001–2002 as a base year. One derived supply point and five derived demand points (two domestic and two exports for fresh red and white, and one for juice) are specifically described in this model. Because juice exports are minimal, the two juice demand points (domestic and export) are considered to be one.

The Lagrangian function associated with the quadratic programming model is

$$\begin{aligned} L = {} & \sum_{v} \sum_{j} \left[\alpha_{vj} Q_{vj}^{D} - \frac{1}{2} \beta_{vj} (Q_{vj}^{D})^2 \right] + \alpha Q_J - \frac{1}{2} \beta \cdot Q_J^2 \\ & - \sum_{v} \sum_{j} PC_j Q_{vj}^{D} - PR \cdot Q_J + \sum_{v} U_v \left[PD_v - \sum_{j} X_{vj} - FR_v \right] \\ & + \sum_{v} \sum_{j} W_{vj} [\lambda_{vj} X_{vj} - Q_{vj}^{D}] + Y \left[\sum_{v} JU \left[\left[\sum_{j} (1 - \lambda_{vj}) X_{vj} \right] + FR_v \right] - Q_J \right]. \end{aligned} \tag{11}$$

The first order conditions associated with the Lagrangian function are

$$\frac{\partial L}{\partial Q_{vj}^D} = \alpha_{vj} - \beta_{vj} Q_{vj}^D - PC_j - W_{vj} \leq 0, \tag{11-1a}$$

$$\frac{\partial L}{\partial Q_{vj}^D} \cdot Q_{vj}^D = 0, \tag{11-1b}$$

$$Q_{vj}^D \geq 0 \tag{11-1c}$$

$$\frac{\partial L}{\partial Q_J} = \alpha - \beta \cdot Q_J - PR - Y \leq 0, \tag{11-2a}$$

$$\frac{\partial L}{\partial Q_J} \cdot Q_J = 0, \tag{11-2b}$$

$$Q_J \geq 0 \tag{11-2c}$$

$$\frac{\partial L}{\partial X_{vj}} = -U_v + W_{vj} \lambda_{vj} + Y \cdot JU(1 - \lambda_{vj}) \leq 0, \tag{11-3a}$$

$$\frac{\partial L}{\partial X_{vj}} \cdot X_{vj} = 0, \tag{11-3b}$$

$$X_{vj} \geq 0 \tag{11-3c}$$

$$\frac{\partial L}{\partial U_v} = PD_v - \sum_j X_{vj} - FR_v \geq 0, \tag{11-4a}$$

$$\frac{\partial L}{\partial U_v} \cdot U_v = 0, \tag{11-4b}$$

$$U_v \geq 0 \tag{11-4c}$$

$$\frac{\partial L}{\partial W_{vj}} = \lambda_{vj} X_{vj} - Q_{vj}^D \geq 0, \tag{11-5a}$$

$$\frac{\partial l}{\partial W_{vj}} \cdot W_{vj} = 0, \tag{11-5b}$$

$$W_{vj} \geq 0 \tag{11-5c}$$

$$\frac{\partial L}{\partial Y} = \sum_v JU\left[\left[\sum_j (1 - \lambda_{vj}) X_{vj}\right] + FR_v\right] - Q_J \geq 0, \tag{11-6a}$$

$$\frac{\partial L}{\partial Y} \cdot Y = 0, \tag{11-6b}$$

$$Y \geq 0 \tag{11-6c}$$

In order to provide an economic interpretation of this system of linear inequalities combined with the complementary slackness conditions, consider first (11-1a) through (11-1c). If $Q_{vj}^D > 0$, then (11-1a) is strictly equal to zero. Rewriting (11-1a) and imposing complementary slackness gives

$$\alpha_{vj} - \beta_{vj} Q_{vj}^D - PC_j = W_{vj} \tag{12}$$

where the left hand side of Equation 12 is the price of variety v shipped to market j adjusted for the cost of packing fruit sent to market j. In other words, $\alpha_{vj} - \beta_{vj} Q_{vj}^D = P_{vj}$ and $P_{vj} - PC_j$ is the net price (NP_{vj}) received (i.e., the price to grove owners measured at the packinghouse input door) for variety v shipped to market j. Let

$$P_{vj} - PC_j = NP_{vj}.$$

So $NP_{vj} = W_{vj}$.

In a similar fashion, consider (11-2a) through (11-2c). Assuming $Q_J > 0$, then

$$\alpha_J - \beta \cdot Q_J - PR = Y$$

and

$$P_J - PR = Y$$

and

$$P_J - PR = NP_J = Y$$

where NP_J is the net price received for juice (i.e., the price to grove owners measured at the packinghouse input door).

Substituting for W_{vj} and Y in (11-3a) and again imposing the assumption that $X_{vj} > 0$ gives

$$NP_{vj} \lambda_{vj} + NP_J JU(1 - \lambda_{vj}) = U_v. \tag{13}$$

The first term on the left hand side of Equation 13 is the return derived from that portion (λ_{vj}) of one unit of harvested fruit that is suitable for the fresh market. The second term on the left hand side of Equation 13 is the return obtained from that portion of one unit $(1 - \lambda_{vj})$ of harvested fruit that is unsuitable for the fresh market and sent to the processing plant. Hence, the Lagrangian multiplier U_v is equal to the return realized from a unit of harvested fruit sent to the packinghouse by growers.

This result implies

$$NP_{vD} \lambda_{vD} + NP_J JU(1 - \lambda_{vD}) = NP_{vE} \lambda_{vE} + NP_J JU(1 - \lambda_{vE}) \tag{14}$$

where the return realized from fruit intended for the export market is equal to the return realized from fruit intended for the domestic market for each variety.

To interpret Equation 14, consider the case where $\lambda_{vD} = \lambda_{vE}$, i.e., the pack-out rate for the domestic market is equal to that for the export market. In this case the net prices are equal, i.e., $NP_{vD} = NP_{vE}$. Furthermore, the FOB packinghouse prices are equal ($P_{vD} = P_{vE}$) when the packing costs are equal for domestic and exported grapefruit ($PC_D = PC_E$). The price in the domestic market P_{vD} is equal to the price in the export market P_{vE}.

In most instances, however, the pack-out rate for the export market is less than the pack-out rate for the domestic market, i.e., $\lambda_{vE} < \lambda_{vD}$. In this case, taking Equation 14 and isolating NP_{vE}, Equation 14 becomes

$$NP_{vE} = \frac{NP_{vD}\,\lambda_{vD} - NP_J\,JU\cdot\lambda_{vD} + NP_J\,JU\cdot\lambda_{vE}}{\lambda_{vE}}. \tag{15}$$

Taking the partial derivative of Equation 15 with respect to λ_{vE} results in

$$\frac{\partial NP_{vE}}{\partial\lambda_{vE}} = \frac{-NP_{vD}\,\lambda_{vD} + NP_J\,JU\cdot\lambda_{vD}}{\lambda_{vE}^2} \tag{16}$$

which is negative when the net price for fresh grapefruit sold domestically times the pack-out rate is greater than the net price per gallon for grapefruit juice times the gallons of juice per box times the pack-out rate ($NP_{vD}\,\lambda_{vD} > NP_J\,JU\cdot\lambda_{vD}$). This is the norm rather than the exception. Fresh grapefruit is worth more than grapefruit juice. This implies that as the export pack-out rate λ_{vE} decreases relative to the domestic pack-out rate λ_{vD}, the net export price increases relative to the net domestic price. The FOB packinghouse price P_{vE} for exported grapefruit is higher than the FOB packinghouse price P_{vD} for domestically consumed grapefruit when $\lambda_{vE} < \lambda_{vD}$ (holding the domestic and export packing costs equal to one another (i.e., $PC_D = PC_E$)). Now we turn our attention to packing costs.

Eliminating the common term $NP_J\,JU$ from both sides of equation (14) and re-arranging gives

$$NP_{vE}\,\lambda_{vE} - NP_{vD}\,\lambda_{vD} = NP_J\,JU(\lambda_{vE} - \lambda_{vD}). \tag{17}$$

To interpret Equation 17, consider the case where $\lambda_{vD} = \lambda_{vE}$, *i.e.*, the pack-out rate for the domestic market is equal to the pack-out rate for the export market. In this case, the net price for fresh grapefruit consumed domestically equals the net price for exported fresh grapefruit ($NP_{vD} = NP_{vE}$). Furthermore, when packing costs for domestic fruit equal the packing costs for exported fruit ($PC_D = PC_E$), not only are net prices for domestic and exported grapefruit equal ($NP_{vD} = NP_{vE}$), the price of grapefruit FOB the packinghouse which is sold domestically equals the FOB price of exported grapefruit ($P_{vD} = P_{vE}$). As packing cost for the export market increases relative to the domestic market (which is the norm), the export price P_{vE} must increase relative to the domestic price P_{vD}. This maintains equality between the two terms on the left-hand side of Equation 17 and the right-hand side which equals zero, when the domestic and export markets have equal pack-out rates ($\lambda_{vE} = \lambda_{vD}$). Thus, there is equal product quality (i.e., $\lambda_{vE} = \lambda_{vD}$) and the FOB packinghouse price for grapefruit consumed domestically is less than the FOB packinghouse price for exported grapefruit ($P_{vD} < P_{vE}$) because the packing cost for exported grapefruit is higher than the packing cost for domestic grapefruit.

Thus, packing cost and pack-out rate are additional reasons why export prices are typically higher than domestic prices. During the 2001–2002 season, the average box price for white seedless grapefruit sent to Japan was $18.26 FOB the packinghouse, while the price for white seedless grapefruit sent to the domestic US market was $13.70 per box (Florida Agricultural Statistics Service [FASS], 2005). As we saw, the Kuhn-Tucker conditions show that when the product characteristics are the same (homogeneous), the FOB prices are equal as in the LOP; however, when product characteristics are not equal (e.g., packing costs and/or pack-out rates are different), the FOB prices are not equal between domestic and exported product because the product characteristics are not equal (nonhomogeneous). A nonlinear programming optimization routine is used to demonstrate the magnitude of the theoretical multi-market equilibrium results.

4. DATA

Demand equations for both red and white fresh domestic grapefruit have been calculated using an average price and quantity plus an estimated price elasticity, assuming a linear demand. The equations for domestic red and white fresh grapefruit are estimated based on an own price elasticity of −0.285. This was calculated using a retail elasticity of −1.113 (Brown & Lee, 2002, p. 25) and multiplied by a price ratio composed of the FOB packinghouse price of $6.85 per 4/5 bushel carton (FASS, 2005) and the retail price of $0.63 per pound times 42.5 pounds per 4/5 bushel carton (USDA, 2003, p. 23). The equations for red and white fresh grapefruit exports to Canada are estimated based on an own price elasticity of −1.67 (Lee, 2004, p. 8). The price elasticity of demand for both fresh red and white grapefruit exported to Europe has been estimated to be −0.39, while that of white and red fresh grapefruit exported to Japan has been estimated to be −0.66 and used in this model (Lee, p. 8). The juice price elasticity of demand is −0.223. This was calculated using a retail elasticity of −1.294 (Brown & Lee, p. 431) and multiplied by a price ratio composed of the processing plant FOB price of $0.86 per single strength equivalent gallon (Florida Citrus Mutual, 2004, p. 46) and the retail of $4.98 per single strength equivalent gallon (Florida Department of Citrus, 2005, p. 64).

The pack-out rates are based on an informal survey by Muraro (Personal Communication, June 10, 2004); however, the pack-out rates used in the model were adjusted in order to calibrate the FOB prices and quantities. The adjusted (Muraro) pack-out rates used are 58 (60) percent for red and 57 (60) percent for white U.S. domestic grapefruit as well as exports to Canada, 50 (58) percent for red and 48 (58) percent for white exports to Europe, and 46 (40) percent for red and 44.5 (35) percent for white exports to Japan.

The processing cost is $0.20 per single strength gallon (Muraro, Spreen, & Pozzan, 2003). Packing cost is $7.09 per 1 and 3/5 bushel box for grapefruit packed for the U.S. and Canadian markets and $7.98 per 1 and 3/5 bushel box for the markets in Europe and Japan (Muraro, 2004a). The number of red grapefruit boxes sent to different markets is 5,273,973 to the U.S., 1,032,630 to Canada, 3,109,616 to Europe, and 3,074,350 to Japan (Florida Department of Agriculture and Consumer Services [FDACS], 2002). The number of white grapefruit 1 and 3/5 bushel boxes sent to different markets is 277,509 to the U.S., 58,831 to Canada, 160,515 to Europe, and 2,538,901 to Japan (FDACS). Single strength gallons of juice produced was 149,100,000 gallons (Florida Department of Citrus, 2005, p. 28) and was sold for $0.86 per single strength gallon (Florida Citrus Mutual, 2004, p. 46).

5. EMPIRICAL RESULTS

The base scenario takes into consideration the differential packing cost and pack-out rate associated with packing for export versus packing for the domestic market and Canada.

TABLE 1. Actual (Simulated) per 1 and 3/5 Bushel Box Prices FOB the Packinghouse for Fresh Grapefruit by Country and Variety for the 2001–2002 Season

Variety/Country	United States	Canada	Europe	Japan
Red	\$12.60[a]	\$12.60	\$16.06	\$17.06
	(\$12.71)[b]	(\$12.71)	(\$16.05)	(\$17.17)
White	\$13.70	\$13.70	\$17.26	\$18.26
	(\$13.49)	(\$13.49)	(\$17.31)	(\$18.43)

[a]Actual (Florida Agricultural Statistics Services, 2005).
[b]Simulated by the multi-market model.

The actual 2001–2002 season average prices FOB the packinghouse, are shown in Table 1. The domestic price is lower than the export price. The packing cost is \$7.09 per 1 and 3/5 bushel box for the US and Canada market and \$7.98 per 1 and 3/5 bushel box for both Europe and Japan (Muraro, 2004a). The adjusted pack-out rates were used.

The model reports output prices FOB the packinghouse. The price calculated by the model for the red variety and the actual average price in the US and Canada shows a gap of \$0.11 or 0.87%, while the difference between the two prices for the white variety comes to \$0.21 or 1.53%. The prices for red grapefruit to Europe and Japan are \$0.01 (0.06%) and \$0.11 (0.64%) difference between the actual and the model price, while the white variety is \$0.05 (0.29%) in Europe and \$0.17 (0.93%) for Japan. Overall, the model fit for domestic markets seams to be slightly less accurate than the fit shown for export markets; however, the model prices deviate from actual prices by less than 1% except the white domestic price which deviates by 1.53%.

5.1 Changes in Packing Costs

In this section, we analyze the impact that changes in packing costs produce on the packinghouse level FOB prices, holding the pack-out rate constant at 60% for all markets. As packing costs increase for US and Canada red grapefruit, holding constant the packing cost for grapefruit sent to Europe and Japan, the FOB packinghouse price for US and Canada red grapefruit increases and the price of red grapefruit destined for Europe and Japan decreases (Table 2). The US and Canada price increases from \$9.08 to \$11.67, for a \$2.59 increase, which is due to a decrease in quantity because of the \$2.00 increase in packing costs. On the other hand, the price for Europe and Japan decreases from \$12.41 to \$11.67, for a \$0.74 decrease, which is due to an increase in quantity because of the \$2.00 increase in packing costs for US and Canadian red grapefruit.

As packing costs increase for US and Canadian white grapefruit, holding constant the packing cost for white grapefruit sent to Europe and Japan, the FOB packinghouse price for US and Canadian white grapefruit increases and the price of white grapefruit destined for Europe and Japan decreases (Table 2). The US and Canadian price increases from \$8.48 to \$11.67, for a \$3.19 increase, which is due to a decrease in quantity because of the \$2.00 increase in packing costs. On the other hand, the price for Europe and Japan decreases from \$11.81 to \$11.67, for a \$0.14 decrease, which is due to an increase in quantity because of the \$2.00 increase in packing costs for US and Canadian grapefruit.

The difference between the red and white grapefruit price increases and decreases is due to the price elasticities (see the Data section) of demand and the quantity of grapefruit

TABLE 2. Simulated FOB Packinghouse Prices per 1 and 3/5 Bushel Box at Different Packing Cost for Fresh Grapefruit Assuming Equal Pack-Out Rates for Domestic and Export Markets[a]

Red grapefruit				White grapefruit			
United States	Canada	Europe	Japan	United States	Canada	Europe	Japan
$9.08	$9.08	$12.41	$12.41	$8.48	$8.48	$11.81	$11.81
5,693.87[b]	1,514.15	3,384.84	3,627.15	307.64	96.55	180.26	3,130.65
($7.00)[c]	($7.00)	($9.00)	($9.00)	($7.00)	($7.00)	($9.00)	($9.00)
$9.44	$9.44	$11.94	$11.94	$9.31	$9.31	$11.81	$11.81
5,650.97	1,464.94	3,420.61	3,683.49	302.84	90.57	180.27	3,130.90
($7.50)	($7.50)	($9.00)	($9.00)	($7.50)	($7.50)	($9.00)	($9.00)
$10.11	$10.11	$11.77	$11.77	$10.11	$10.11	$11.77	$11.77
5,571.60	1,373.89	3,433.29	3,703.48	298.25	84.86	180.41	3,134.41
($8.00)	($8.00)	($9.00)	($9.00)	($8.00)	($8.00)	($9.00)	($9.00)
$10.89	$10.89	$11.72	$11.72	$10.89	$10.89	$11.72	$11.72
5,478.36	1,266.93	3,437.20	3,709.63	293.74	79.23	180.59	3,139.16
($8.50)	($8.50)	($9.00)	($9.00)	($8.50)	($8.50)	($9.00)	($9.00)
$11.67	$11.67	$11.67	$11.67	$11.67	$11.67	$11.67	$11.67
5,385.12	1,159.97	3,441.11	3,715.78	289.23	73.61	180.78	3,143.91
($9.00)	($9.00)	($9.00)	($9.00)	($9.00)	($9.00)	($9.00)	($9.00)

[a]Pack-out rate equals 60%.
[b]Quantity produced in thousand 1 and 3/5 bushel boxes.
[c]Packing cost per 1 and 3/5 bushel box.

sold to each country. The number of red grapefruit 1 and 3/5 bushel boxes sent to different markets in 2001–2002 is 5,273,973 to the U.S., 1,032,630 to Canada, 3,109,616 to Europe, and 3,074,350 to Japan (FDACS, 2002). The number of white grapefruit 1 and 3/5 bushel boxes sent to different markets in 2001–2002 is 277,509 to the U.S., 58,831 to Canada, 160,515 to Europe, and 2,538,901 to Japan (FDACS). For red grapefruit, the US (domestic market) and Canada (treated as a domestic market) consumed 6,306,500 boxes and Europe and Japan (export markets) consumed 6,184,000 boxes, almost equal quantities. For white grapefruit, the US and Canada consumed 336,500 boxes and Europe and Japan consumed 2,699,500 boxes, a large difference in market share.

5.2 Changes in Pack-Out Rates

In this section, we analyze the impact that changes in pack-out rate produce on the packinghouse level FOB prices. First, we estimate the impact of changes in pack-out rate, holding the packing costs constant at $7.90 per box for all markets. As the pack-out rate increases for US and Canada red grapefruit, holding constant the pack-out rate for grapefruit sent to Europe and Japan, the FOB packinghouse price for US and Canada red grapefruit decreases and the price of red grapefruit destined for Europe and Japan also decreases (Table 3). The US and Canada price decreases from $21.43 to $10.33, for a $11.10 decrease, which is due to an increase in quantity because of the 40% increase in pack-out rate. The price for Europe and Japan decreases from $21.43 to $17.43, for a $4.00 decrease, which is due to an increase in quantity because of the 40% increase in pack-out rate for US and Canadian red grapefruit.

TABLE 3. Simulated per 1 and 3/5 Bushel Box Prices FOB the Packinghouse for Fresh Grapefruit at Different Pack-Out Rates and Equal Packing Cost ($7.90 per 1 and 3/5 Bushel Box)

Red grapefruit				White grapefruit			
United States	Canada	Europe	Japan	United States	Canada	Europe	Japan
$21.43	$20.15	$21.43	$21.43	$21.34	$21.34	$21.34	$21.34
4,220.89[a]	0	2,704.16	2,554.96	233.43	4.09	145.72	2,256.77
(40%)[b]	(40%)	(40%)	(40%)	(40%)	(40%)	(40%)	(40%)
$17.09	$17.09	$20.93	$20.93	$17.36	$17.36	$21.27	$21.27
4,738.21	417.86	2,741.45	2,613.70	256.37	32.68	145.96	2,262.80
(50%)	(50%)	(40%)	(40%)	(50%)	(50%)	(40%)	(40%)
$14.11	$14.11	$20.01	$20.01	$14.83	$14.83	$21.10	$21.10
5,093.49	825.43	2,810.93	2,723.14	270.96	50.85	146.60	2,278.87
(60%)	(60%)	(40%)	(40%)	(60%)	(60%)	(40%)	(40%)
$11.93	$11.93	$18.76	$18.76	$13.15	$13.15	$20.90	$20.90
5,354.33	1,124.65	2,905.55	2,872.19	280.67	62.95	147.29	2,296.37
(70%)	(70%)	(40%)	(40%)	(70%)	(70%)	(40%)	(40%)
$10.33	$10.33	$17.43	$17.43	$11.98	$11.98	$20.73	$20.73
5,544.64	1,342.96	3,005.92	3,030.29	287.44	71.38	147.93	2,312.67
(80%)	(80%)	(40%)	(40%)	(80%)	(80%)	(40%)	(40%)

[a]Quantity produced in thousand 1 and 3/5 bushel boxes.
[b]Pack-out rate.

As pack-out rate increases for US and Canada white grapefruit, holding constant the pack-out rate for white grapefruit sent to Europe and Japan, the FOB packinghouse price for US and Canadian white grapefruit decreases and the price of white grapefruit destined for Europe and Japan also decreases (Table 3). The US and Canadian price decreases from $21.34 to $11.98, for a $9.36 decrease, which is due to an increase in quantity because of the 40% increase in pack-out rate. The price for Europe and Japan decreases from $21.34 to $20.73, for a $0.61 decrease, which is due to an increase in quantity because of the 40% increase in pack-out rate for US and Canadian grapefruit.

6. SUMMARY AND CONCLUSIONS

This article uses a theoretical model to show how the impact of a nonhomogeneous product affects the LOP. A nonlinear programming optimization routine is used to demonstrate the magnitude of the theoretical results. The FOB packinghouse price for the domestic market is lower that the price for the export market. It is demonstrated that product characteristics, such as packing costs and pack-out rates, are important factors behind this deviation of FOB prices. Prices show that deviations from the LOP are to be expected for an agricultural product in which packing costs and pack-out rates differ between domestic and export markets because the product is heterogeneous and not homogeneous. Furthermore, we can state that differences in FOB prices can be found in any agricultural product that explicitly has pack-out rates and packing costs that differ; therefore, the products are not homogeneous.

An implication of these findings is that products across countries may not be homogenous and should not obey the LOP. The LOP may be violated for the wrong reason. The correct reason is that the product is not homogeneous. Packing costs in the country of origin could differ based on the requirements of the export market. This causes prices among countries to be different. Thus, the price data collected for research into the LOP will contain differences based on differences in product characteristics (i.e., packing cost differences). Packing cost differences among products can be determined by going to packinghouses in the country of origin.

A second implication of these findings is that products may have differences in quality that can only be found by meticulous comparison of the products among countries. Seemingly homogenous products across countries may not be homogenous and should not obey the LOP. Quality differences among countries (i.e., pack-out rate differences) cause prices among countries to be different. Thus, the price data collected for research into the LOP may contain differences based on differences in quality. Research into the LOP will require more than price data. It will take additional research into the product's characteristics to determine if the products are homogeneous.

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