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# DEMAND FOR OJ, BY PRODUCT FORM, IN A CONDITIONAL DEMAND SYSTEM FOR BEVERAGES, AND SENSITIVITY OF PRODUCT FORMS TO SUPPLY


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## Abstract

Demands for orange juice by product form are estimated, and own- and cross-price elasticity estimates are used to examine how supply changes impact retail prices and quantity sales, by form. The retail price for each form is dependent on the grower or ingredient price for orange juice. This price is dependent on the total supply of OJ, and, in turn, is a major factor determining the retail prices, and, hence, the associated quantities demanded at the retail level.



*Key Words:* orange juice, demand, Rotterdam model.

# Demand for OJ, By Product Form, In a Conditional Demand System for Beverages And Sensitivity of Product Forms to Supply

## Introduction

The overall demand for orange juice (OJ) is comprised of demands for many different products. These products can be grouped into four basic forms---1) frozen concentrated orange juice (FCOJ), 2) not-from-concentrate orange juice (NFC), 3) reconstituted orange juice (RECON), and 4) shelf stable orange juice (SSOJ). The retail price for the various OJ products, as well as the average price for each form, is dependent on the grower or ingredient price for OJ. The grower price is dependent on the total supply of OJ, and, in turn, is a major factor determining the retail prices, and, hence, the associated quantities demanded at the retail level.

This paper presents some own- and cross-price elasticity estimates for the four OJ product forms, and examines how supply changes impact retail prices and quantity sales, by form.

## Rotterdam Model

The Rotterdam model (Theil 1971, 1975, 1976, 1980a, 1980b) is a system of differential demand equations. These equations are directly related to the utility maximization problem confronting consumers---how to allocate income over available goods. The solution is the affordable bundle of goods that yields the greatest utility. The (unconditional) problem can be written as maximization of $u = u(q)$ subject to $p'q = x$, where u is utility; $p' = (p_1, \ldots, p_n)$ and q'

$= (q_1, \ldots, q_n)$ are price and quantity vectors with $p_i$ and $q_i$ being the price and quantity of good i, respectively; and x is total expenditures or income. The first order conditions for this problem are $\partial u/\partial q = \lambda p$ and $p'q = x$, where $\lambda$ is the Lagrange multiplier which is equal to $\partial u/\partial x$ or the marginal utility of income. The solution to the first order conditions is the set of demand equations $q = q(p, x)$, and the Lagrange multiplier equation $\lambda = \lambda(p, x)$. The Rotterdam demand model is an approximation of this set of demand equations.

Assuming separability, we focus on the conditional demands for a subset of 15 beverages. Following Theil (1976, 1980b), the conditional Rotterdam (differential) demand equation for beverage i can be written as

(1) $$w_i \, d(\log q_i) = \theta_i \, d(\log Q) + \sum_j \pi_{ij} \, d(\log p_j) + \beta_i,$$

$i=1, \ldots, 15,$

where now subscript i stands for a beverage; $p_i$ and $q_i$ are the price and quantity of beverage i, respectively; $w_i = p_i q_i / x$ or the budget share for beverage i, with $x = \sum_i p_i q_i$ or total expenditures on the 15 beverages or conditional income (referred to as income, for short); $\theta_i = p_i(\partial q_i / \partial x)$ is the marginal propensity to consume (MPC) for beverage i; $d(\log Q) = \sum_i w_i \, d(\log q_i)$ is the Divisia volume index or change in real income; $\pi_{ij} = (p_i p_j / x) k_{ij}$ is the Slutsky coefficient, with $k_{ij} = (\partial q_i / \partial p_j + q_j \, \partial q_i / \partial x)$ being the $(i,j)^{th}$ substitution effect; and $\beta_i$ is a constant to account for trends in sales of beverage i.

The general restrictions on demand, imposed as part of our maintained hypothesis, are (e.g., Theil 1980a, 1980b)

(2) adding up: $\sum_i \theta_i = 1, \qquad \sum_i \pi_{ij} = 0, \qquad \sum_i \beta_i = 0,$

(3) homogeneity: $\sum_j \pi_{ij} = 0;$

(4) symmetry: $\pi_{ij} = \pi_{ji}$.

## Application

Conditional demands for beverages were studied using Nielsen data based on retail scanner sales for grocery stores, drug stores, mass merchandisers along with an estimate of Wal-Mart sales based on a consumer panel. Fifteen beverages, four 100% OJ product forms and eleven other beverages, were included in the model: 1) frozen concentrated orange juice (FCOJ), 2) not-from-concentrate orange juice (NFC), 3) reconstituted orange juice (RECON), 4) shelf stable orange juice (SSOJ), 5) 100% grapefruit juice, 6) 100% apple juice ,7) 100% grape juice, 8) remaining 100% juice, 9) vegetable juice, 10) less-than-100% juice drinks, 11) carbonated water, 12) water, 13) liquid tea, 14) regular and diet soda, and 15) milk and shakes.

The data are weekly, running from week ending June 28, 2003 through week ending June 3, 2006 (154 weekly observations). The raw data were comprised of gallon and dollar sales. In our application, quantity demanded was measured by per capita gallon sales, obtained by dividing raw gallon sales by the U.S. population; prices were obtained by dividing dollar sales by gallon sales.

The infinitely small changes in the logarithms of quantities and prices in the differential model were measured by discrete first differences (Theil 1975, 1976). )---$d(\log q_{it}) = \log q_{it} - \log q_{it-1}$, $d(\log p_{it}) = \log p_{it} - \log p_{it-1}$. To account for seasonality, first differences of sine and cosine variables were also included—$\sin(2\pi t/52)$ and $\text{cosine}(2\pi t/52)$ where $\pi = 3.14...$, observation $t = 1, ..., 154$ and 52 is the number of weeks in a year. Average budget share values underlying the differencing were used in constructing the model variables—$w_{i,t}$ was replaced by $(w_{i,t} + w_{i,t-1})/2$.

The demand specifications studied are conditional on expenditure or income allocated to the 15 beverage categories. Income allocated to the beverage group is measured by the conditional Divisia volume index for this group which was treated as independent of the error term added to each beverage-demand equation for estimation, based on the theory of rational random behavior (Theil 1980a; Brown, Behr and Lee). As the data add up by construction---the left-hand-side variables in the Rotterdam model sum over i to the conditional Divisia volume index--the error covariance matrix was singular and an arbitrary equation was excluded (the model estimates are invariant to the equation deleted as shown by Barten, 1969). The parameters of the excluded equation can be obtained from the adding-up conditions or by re-estimating the model omitting a different equation. The equation error terms were assumed to be contemporaneously correlated and the full information maximum likelihood procedure (TSP) was used to estimate the system of equations.

Estimates of the conditional income or expenditure elasticities and uncompensated price elasticities are shown in Table 1, and associated p-values (probabilities greater than the absolute value of the t statistic) are shown in Table 2.

**Impacts of Orange Juice Supply on Prices and Quantities, By Product Form**

The demand estimates for OJ can be used to examine an issue facing the U.S. OJ industry---if OJ production is reduced as a result of huanglongbing (HLB) or citrus greening, how will prices and demands for OJ, by product form, be impacted. The total demand for OJ, which is the sum of demands across the four product forms, can be written as

(5) $$q = \sum_{i=1 \text{ to } 4} q_i(p_1, p_2, p_3, p_4).$$

It is assumed that total conditional beverage expenditures and beverage prices other than those for the four OJ product forms are constant.

A change in OJ production will tend to result in a change in the grower price for OJ (p), and, in turn, retail prices for OJ can be expected to change. Retail prices can be linked to the grower price for OJ by specifying

(6) $$p_j = p + m_j,$$

where $m_j$ is the margin between the grower price and the retail price for product form j. It is assumed that same delivered-in price applies to each product form, based on the argument that, if not so, returns could be increased by reallocating pound solids from use in a low priced form to use in a higher priced one. The decreased utilization for the low priced form would tend to increase the price for this form, while the increased utilization for the high priced form would tend to decrease its price, assuming negatively sloped demand curves for the product forms. This process would continue until the delivered-in price was the same across forms. In the case there were some persistence difference in the delivered-in price between product forms, the difference could be included as part of the price margin (m).

Consider the amount of OJ available for consumption in the U.S. which is denoted by Q. This amount is comprised of U.S. production of OJ plus imports, largely from Brazil, the world's largest producer of OJ. Since HLB is present in Brazil, it is assumed that a reduction in U.S. OJ production due to HLB will be matched by proportional reductions in Brazil's production and exports to the U.S.

Consider the OJ supply-demand equilibrium, Q = q, or, in terms of the product form demands,

(7) $$Q = \sum_{i=1 \text{ to } 4} q_i(p_1, p_2, p_3, p_4).$$

Based on the grower-retail price linkage equation (6), the total differential of equation (7) with respect to the grower price (p) is

(8) $$dQ = \sum_i \sum_j (\partial q_i/\partial p_j)\, dp,$$

or, in terms of elasticities, found by dividing both side of equation (8) by Q or equivalently q, and multiplying and dividing the right-hand-side of equation (8) by p $p_j$ $q_i$),

(9a) $$dQ/Q = \sum_i (q_i/q) \sum_j (\partial q_i/\partial p_j)\, (p_j/q_i)\, (p/p_j)\, (dp/p),$$

or

(9b) $$dQ/Q = \sum_i w_i \sum_j \varepsilon_{ij}\, (p/p_j)\, (dp/p),$$

or

(9c) $$dQ/Q = \sum_i w_i \sum_j \varepsilon^0_{ij}\, (dp/p),$$

where $w_i = q_i/q$; $\varepsilon_{ij}$ is the retail price elasticity for product form i with respect to the price of product from j; and $\varepsilon^0_{ij} = \varepsilon_{ij}\,(p/p_j)$, i.e., the retail elasticity times the grower-retail price ratio, or the price elasticity at the grower level corresponding to $\varepsilon_{ij}$.

Rearranging and letting $\varepsilon^0 = \sum_i w_i \sum_j \varepsilon^0_{ij}$, equation (9c) can be written as

(10) $$dp/p = (dQ/Q)\, /\varepsilon^0.$$

The term $\varepsilon^0$ is the overall price elasticity of demand for OJ at the grower level.

Equation (10) indicates the percentage change in the grower price (dp/p) for some percentage change in U.S. supply (dQ/Q).

The percentage change in the demand for OJ product form i can be written as

(11) $$dq_i/q_i = \sum_j \varepsilon^0_{ij}\, (dp/p).$$

Substituting the right-hand-side of equation (10) for dp/p in equation (11) yields,

(12) $$\varepsilon_{iQ} = (\sum_j \varepsilon^0_{ij})/\, \varepsilon^0,$$

where $\varepsilon_{iQ} = (dq_i/q)/(dQ/Q)$ or the elasticity of demand for product form i with respect to supply.

Based on equation (8) and given dq = DQ (supply changes equal demand changes), we also find with respect to demand at the retail level

(13) $$dq = \sum_i \sum_j (\partial q_i/\partial p_j)\, dp,$$

or

(14) $$(dq/dp) = \sum_i \sum_j (\partial q_i/\partial p_j),$$

or

(15) $$\varepsilon^r = (p_{oj}/q)(\sum_i \sum_j (\partial q_i/\partial p_j)),$$

where $p_{oj}$ is the overall retail price for OJ (a weighted average of product form prices) and $\varepsilon^r = (dq/dp)\,(p_{oj}/q)$ is overall price elasticity for OJ demand at the retail level.

Results are shown in Table 3. The retail own-price elasticities, by OJ product forms, are negative and relatively large (in absolute value) ranging from -1.75 for SSOJ to -1.99 for FCOJ. The retail cross-price elasticities are positive and relatively large with respect to substitution between NFC and RECON, and with respect to the RECON price in the FCOJ demand equation. The overall OJ price elasticity is -1.38, which is larger in absolute value than estimates usually obtained when the overall quantity of OJ is related to the (quantity) weighted average price of OJ. This result may be related to multicollinearity among prices which reduces the precision of the elasticity estimates.

The own- and cross-price elasticities at the grower level, by product form, are significantly lower than the corresponding elasticities at the retail level, given the grower-retail price ratios rage form .22 to .35. The overall grower price elasticity for OJ is estimated at -.39.

The elasticity of quantity demanded ($q_i$) with respect to supply (Q), by product form, is relatively low for NFC and relatively high for FCOJ and RECON. A 50.0% reduction in supply would result in a 35.8% decrease in NFC demand, and 68.5% and 63.6% decreases in FCOJ and RECON demands, respectively.

## Concluding Comments

Based on comprehensive retail data on the demand for OJ and its major substitutes, this study found some relatively large own- and cross price elasticities of demand for OJ, by product form. The elasticities for the OJ product forms were used to analyze the impact of supply shifts on the demands for OJ by product form. It was found that a supply shift had the largest percentage impact on FCOJ and RECON and the smallest impact on NFC.

It should be noted that the above results are related to own- and cross-price effects alone. Other separate impacts related to income, promotion/advertising and other factors could also occur, perhaps offsetting these results. Additionally, the estimated price elasticities used in this study may not fully reflect what might occur given such a large supply change considered and associated price changes are outside the range of the data used in estimating the model.

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Table 1. Beverage Demand Elasticity Estimates.

| | Cond. Income Elast. | Price Elasticity (Uncompensated) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FCOJ | NFC | RECON | SSOJ | Grapefruit | Apple | Grape | Rem. Fruit J. | Veg. | Juice Drinks | Carb. Water | Water | Tea | Soda | Milk & Shakes |
| FCOJ | 1.009 | -1.992 | 0.094 | 0.292 | -0.015 | 0.110 | 0.101 | 0.005 | 0.093 | 0.156 | -0.022 | -0.040 | 0.114 | 0.073 | -0.010 | 0.006 |
| NFC | 0.978 | 0.012 | -1.846 | 0.416 | 0.002 | 0.003 | -0.038 | 0.059 | 0.078 | 0.074 | 0.038 | 0.036 | 0.228 | 0.012 | 0.357 | -0.409 |
| RECON | 0.657 | 0.058 | 0.665 | -1.902 | 0.001 | 0.013 | 0.159 | 0.021 | 0.136 | 0.004 | 0.087 | 0.040 | -0.356 | -0.022 | 0.748 | -0.310 |
| SSOJ | 0.787 | -0.092 | 0.119 | 0.037 | -1.751 | 0.126 | -0.172 | 0.298 | 0.607 | 0.301 | -0.571 | -0.166 | 0.182 | 0.361 | 0.677 | -0.743 |
| Grapefruit | 0.869 | 0.177 | 0.050 | 0.099 | 0.031 | -1.829 | 0.001 | -0.005 | 0.280 | -0.046 | -0.551 | 0.027 | 0.543 | 0.227 | 0.653 | -0.527 |
| Apple | 0.926 | 0.028 | -0.082 | 0.218 | -0.007 | 0.000 | -2.315 | 0.021 | -0.074 | 0.036 | 0.382 | -0.019 | -0.027 | -0.101 | 0.584 | 0.432 |
| Grape | 0.951 | 0.003 | 0.276 | 0.053 | 0.026 | -0.002 | 0.044 | -1.783 | 0.264 | 0.011 | -0.606 | -0.075 | 0.244 | 0.371 | 0.844 | -0.623 |
| Rem. Fruit J. | 0.792 | 0.019 | 0.130 | 0.133 | 0.018 | 0.034 | -0.050 | 0.091 | -1.862 | 0.118 | -0.239 | -0.008 | 0.311 | 0.163 | 0.568 | -0.217 |
| Vegetable | 1.046 | 0.057 | 0.217 | -0.002 | 0.017 | -0.011 | 0.046 | 0.006 | 0.217 | -1.990 | -0.892 | -0.004 | 0.000 | 0.399 | 1.050 | -0.157 |
| Juice Drinks | 1.182 | -0.002 | 0.004 | 0.005 | -0.004 | -0.015 | 0.052 | -0.045 | -0.060 | -0.101 | -1.099 | 0.013 | -0.076 | -0.070 | 0.611 | -0.396 |
| Carb. Water | 1.026 | -0.040 | 0.114 | 0.073 | -0.010 | 0.006 | -0.029 | -0.053 | -0.022 | -0.005 | 0.149 | -1.601 | 0.144 | 0.036 | 0.614 | -0.403 |
| Water | 1.139 | -0.005 | 0.100 | -0.119 | 0.001 | 0.019 | -0.010 | 0.023 | 0.083 | -0.001 | -0.102 | 0.019 | -1.751 | 0.065 | 0.993 | -0.455 |
| Tea | 1.348 | -0.020 | 0.009 | -0.047 | 0.014 | 0.034 | -0.102 | 0.161 | 0.198 | 0.270 | -0.455 | 0.019 | 0.265 | -0.437 | -0.549 | -0.710 |
| Soda | 1.217 | 0.009 | 0.032 | 0.042 | 0.001 | 0.005 | 0.026 | 0.019 | 0.032 | 0.039 | 0.213 | 0.020 | 0.244 | -0.029 | -2.051 | 0.181 |
| Milk & Shakes | 0.631 | -0.004 | -0.047 | -0.029 | -0.002 | -0.005 | 0.035 | -0.017 | -0.017 | -0.002 | -0.112 | -0.014 | -0.102 | -0.038 | 0.433 | -0.709 |

Table 2. P-Values for Beverage Demand Elasticity Estimates.

| | Cond. Income Elast. Prob \|t\| | Price Elasticity (Uncompensated): Prob \|t\| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FCOJ | NFC | RECON | SSOJ | Grapefruit | Apple | Grape | Rem. Fruit J. | Veg. | Juice Drinks | Carb. Water | Water | Tea | Soda | Milk & Shakes |
| FCOJ | [.000] | [.000] | [.279] | [.006] | [.511] | [.046] | [.188] | [.964] | [.512] | [.192] | [.876] | [.397] | [.060] | [.335] | [.315] | [.820] |
| NFC | [.000] | [.276] | [.000] | [.000] | [.363] | [.608] | [.310] | [.004] | [.019] | [.009] | [.722] | [.059] | [.128] | [.794] | [.001] | [.005] |
| RECON | [.000] | [.005] | [.000] | [.000] | [.769] | [.255] | [.008] | [.610] | [.022] | [.932] | [.534] | [.276] | [.063] | [.772] | [.000] | [.068] |
| SSOJ | [.000] | [.516] | [.326] | [.788] | [.000] | [.445] | [.081] | [.055] | [.003] | [.058] | [.002] | [.324] | [.503] | [.006] | [.000] | [.001] |
| Grapefruit | [.000] | [.045] | [.570] | [.281] | [.446] | [.000] | [.984] | [.964] | [.024] | [.656] | [.000] | [.805] | [.004] | [.008] | [.000] | [.001] |
| Apple | [.000] | [.182] | [.319] | [.010] | [.076] | [.996] | [.000] | [.604] | [.222] | [.509] | [.017] | [.610] | [.900] | [.212] | [.000] | [.027] |
| Grape | [.000] | [.960] | [.004] | [.656] | [.057] | [.958] | [.607] | [.000] | [.050] | [.927] | [.000] | [.456] | [.308] | [.001] | [.000] | [.002] |
| Rem. Fruit J. | [.000] | [.486] | [.012] | [.026] | [.003] | [.023] | [.243] | [.047] | [.000] | [.029] | [.006] | [.865] | [.012] | [.004] | [.000] | [.043] |
| Vegetable | [.000] | [.194] | [.009] | [.988] | [.061] | [.639] | [.528] | [.935] | [.035] | [.000] | [.000] | [.951] | [.999] | [.000] | [.000] | [.385] |
| Juice Drinks | [.000] | [.763] | [.903] | [.875] | [.001] | [.000] | [.030] | [.000] | [.001] | [.000] | [.000] | [.223] | [.484] | [.015] | [.000] | [.001] |
| Carb. Water | [.000] | [.397] | [.060] | [.335] | [.315] | [.820] | [.585] | [.450] | [.813] | [.954] | [.153] | [.000] | [.345] | [.606] | [.000] | [.001] |
| Water | [.000] | [.671] | [.149] | [.037] | [.577] | [.006] | [.833] | [.340] | [.024] | [.970] | [.501] | [.380] | [.000] | [.247] | [.000] | [.038] |
| Tea | [.000] | [.429] | [.922] | [.638] | [.008] | [.011] | [.178] | [.001] | [.007] | [.000] | [.010] | [.672] | [.282] | [.001] | [.003] | [.001] |
| Soda | [.000] | [.000] | [.029] | [.000] | [.014] | [.000] | [.004] | [.000] | [.000] | [.000] | [.000] | [.000] | [.000] | [.012] | [.000] | [.001] |
| Milk & Shakes | [.000] | [.213] | [.022] | [.064] | [.001] | [.004] | [.006] | [.005] | [.097] | [.799] | [.033] | [.016] | [.131] | [.013] | [.000] | [.000] |

Table 3. Price elasticities for OJ demand, by product form.

| | Retail Price Elasticity ($\varepsilon_{ij}$) | | | |
|---|---|---|---|---|
| Product Form/Price | FCOJ | NFC | RECON | SSOJ |
| FCOJ | -1.99 | 0.09 | 0.29 | -0.01 |
| NFC | 0.01 | -1.85 | 0.42 | 0.00 |
| RECON | 0.06 | 0.67 | -1.90 | 0.00 |
| SSOJ | -0.09 | 0.12 | 0.04 | -1.75 |

Overall OJ Price Elasticity at Retail Level ($\varepsilon^r = \sum_i w_i \sum_j (p_{oj}/p_j)\varepsilon_{ij}$)

-1.38

| | Grower-Retail Price Ratio ($p/p_j$) | | | |
|---|---|---|---|---|
| | FCOJ | NFC | RECON | SSOJ |
| | $/SSE Gallon | | | |
| Grower Price | 1.50 | 1.50 | 1.50 | 1.50 |
| Retail Price | 4.56 | 6.44 | 4.26 | 6.82 |
| G/R Price Ratio | 32.9% | 23.3% | 35.2% | 22.0% |

| | Grower Price Elasticity ($\varepsilon^0_{ij} = (p/p_j)\varepsilon_{ij}$) | | | | Quantity Wt. ($w_i$) |
|---|---|---|---|---|---|
| FCOJ | -0.66 | 0.02 | 0.10 | 0.00 | 6.3% |
| NFC | 0.00 | -0.43 | 0.15 | 0.00 | 49.7% |
| RECON | 0.02 | 0.15 | -0.67 | 0.00 | 43.4% |
| SSOJ | -0.03 | 0.03 | 0.01 | -0.39 | 0.6% |

OJ Price Elasticity at Grower Level ($\varepsilon^0 = \sum_i w_i \sum_j \varepsilon^0_{ij}$)

-0.39

Quantity Elasticity wrt Supply ($\varepsilon_{iQ}$)

| | Elasticity ($\varepsilon_{iQ}$) | Assumed% Chg Q | Est. % Chg $q_i$ |
|---|---|---|---|
| FCOJ | 1.37 | -50.0% | -68.5% |
| NFC | 0.72 | -50.0% | -35.8% |
| RECON | 1.27 | -50.0% | -63.6% |
| SSOJ | 0.96 | -50.0% | -48.1% |