Does Advertising Rotate Demand Curves? Some Evidence for U.S. Non-Alcoholic Beverages*

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Short abstract: This paper tests for price-advertising interaction effects in the U.S. non-alcoholic beverage market using various forms of the Rotterdam model. Results are mixed in that some models reject the null hypothesis of no rotation while others do not. One explanation for the mixed results may be multicollinearity problems in the less restrictive models.

Abstract

Building on earlier work by Cramer, this paper tests for price-advertising interaction effects in the U.S. non-alcoholic beverage market. Full and restricted specifications of the Rotterdam model are tested along with compensated and first difference double-log models using annual time-series data for the period 1970-2000. Results are mixed in that the full Rotterdam and first difference double-log models fail to reject the null hypothesis of no rotation while the restricted Rotterdam and compensated double-log models indicate rejection. One reason for the ambiguous results may be multicollinearity problems associated with the unrestricted models. Still, our overall conclusion is that there is little solid evidence to suggest that generic advertising rotated the demand curves for non-alcoholic beverages in the United States.

Key words: advertising, demand elasticities, interaction effects, Rotterdam model

Does Generic Advertising Rotate Demand Curves? Some Evidence for U.S. Non-Alcoholic Beverages

Despite a long-standing hypothesis that the advertising of farm products alters demand elasticities (Waugh; Quilkey), and the importance of the hypothesis for allocation decisions (Chung and Kaiser) and producer returns (Zhang and Sexton), virtually no research exists to test the hypothesis. The only known test in the agricultural economics literature is the study of domestic cotton promotion by Ding and Kinnucan in which the hypothesis of curve rotation was rejected. Although this result may be indicative, in the marketing literature where the hypothesis has received greater attention there is evidence that advertising can indeed influence consumers' sensitivity to price. In particular, Wittink found that of 20 studies that addressed the issue 15 showed evidence of curve rotation, with seven indicating a more elastic demand due to advertising and eight a less elastic demand.

The purpose of this research is to determine whether advertising alters the demand elasticities for non-alcoholic beverages. Non-alcoholic beverages is a useful test case in that at $1.2 billion per year this is one of the most heavily advertised commodity groups in the United States. Two of the products in the group, fluid milk and juices, are the target of significant generic advertising funded by producer checkoffs, amounting to some $200 million in 2003. Recent research by Kinnucan *et al*. firmly rejects the hypothesis that non-alcoholic beverage advertising has no effect on the *level* of demand for the individual beverages. What is not known is whether the advertising affects the slopes of the demand curves. Given the firm rejection of no shift effect, this would appear to be an especially promising group in which to test whether there is a rotation effect.

Prior to model specification we distinguish between curve rotation and elasticity change and derive some propositions about price-advertising interaction using Frisch's duality relationship. The results of the hypothesis tests are then presented with four models employing time-series data: a double-log model in levels and first differences a là Alston *et al*. and Cramer, respectively; and a Rotterdam model with and without the Tintner-Basmann restrictions a là Selvanathan. The paper concludes with a brief summary of the key findings.

Curve Rotation and Elasticity Change

The effect of advertising on the demand elasticity depends on the extent to which the advertising rotates the demand curve, but also on the shift in the curve. In fact, curve rotation is neither necessary nor sufficient for advertising to alter the demand elasticity. Since this is important for empirical testing, it bears analysis. For this purpose, let the market demand elasticity be defined as follows:

(1) $$\eta = \Delta\, (p^o/q^o)$$

where $\Delta = -\,(\partial q/\partial p)$ is the demand curve's slope in absolute value, and p^o and q^o are price and quantity, respectively, in competitive equilibrium. Taking the logarithmic total differential of (1) with respect to advertising expenditure a yields:

(2) $$d \ln \eta/d \ln A = d \ln \Delta/d \ln A + d \ln p^o/d \ln A - d \ln q^o/d \ln A.$$

From (2) advertising's effect on the demand elasticity can be decomposed into three components: a rotation effect ($d \ln \Delta/d \ln A$), a price effect ($d \ln p^o/d \ln A$), and a quantity effect ($d \ln q^o/d \ln A$). Since the components enter additively, a non-zero value for any one of them is sufficient to cause the demand elasticity to change. For example, in the simple case where advertising rotates the demand curve about the initial equilibrium point (p^o, q^o) the price and quantity effects vanish and the sign of (2) depends strictly on the direction of curve rotation. A clockwise rotation, for example, implies that $d \ln \Delta/d \ln A < 0$, which means in this instance means that $d \ln \eta/d \ln A < 0$, i.e., demand is made less elastic. Conversely, if advertising shifts the demand curve without rotating it, the demand elasticity will still change provided the quantity and price effects are unequal, i.e., the slope of the supply curve in the relevant range is not unitary elastic.

In an econometric setting curve rotation is likely to be accompanied by a shift in the curve. To analyze this more complex situation, we assume for simplicity that prices are exogenous, a not atypical finding in the empirical literature (e.g., Brester and Schroeder; Kinnucan *et al*. 1997). In this instance, (2) reduces to:

(3) $$\partial \ln \eta/\partial \ln A = \partial \ln \Delta/\partial \ln A - \alpha$$

where $\alpha = \partial \ln q/\partial \ln A$ is the *horizontal* relative shift in the demand curve due to a small change in advertising, i.e., the shift in the quantity direction holding prices constant. Because this "shift effect" (commonly known as the "advertising elasticity") is generally positive, it will either reinforce or offset the rotation effect depending on the latter's sign. For example, if $\partial \ln \Delta/\partial \ln A > 0$, as might be expected if advertising stresses a product's "substitutability for other products in its end uses" (Quilkey, p. 51), the effect of this type of advertising on the demand elasticity is ambiguous, dependent on the relative magnitude of α. Conversely, if $\partial \ln \Delta/\partial \ln A < 0$, as might be expected if advertising stresses uniqueness of a product (the other scenario considered by Quilkey), then $\partial \ln \eta/\partial \ln A$ is unambiguously negative in the presence of a positive shift effect. The upshot is that the shift effect complicates the interpretation of advertising's effect on the demand elasticity, especially in situations where the advertising is designed to make demand more price elastic. Stated differently, the shift effect prejudices results in favor of showing that the advertising made demand *less* price elastic, regardless of the advertising's original intent.

Additional insight can be obtained by noting that the second-order cross partial derivatives of any particular function are unaffected by the order in which the derivative is taken. Thus, in the simple case where quantity demanded q_D is defined to be a function of price and advertising as follows:

(4) $$q_D = D(p, A)$$

the following "duality relation" (Frisch, p. 180) holds:

$$\partial^2 D/\partial p\, \partial A = \partial^2 D/\partial A\, \partial p.$$

or, in elasticity notion,

(5) $$\partial\eta/\partial \ln A = - \partial\alpha/\partial \ln p$$

where η is (as before) interpreted as an absolute value. Thus, if advertising has no effect on the demand elasticity, then by (5) it must also be true that price has no on the advertising elasticity. The latter inference contradicts a basic assumption underlying Chung and Kaiser's analysis, namely that advertising would be more effective at shifting the demand curve when prices are low than when prices are high. As noted by Frisch (p. 180) equations such as (5) are invariant under a general (non-linear) transformation of the utility function. Hence, the hypothesis based on (5) that the advertising-price interaction effect should be non-zero is quite general.

Empirical Models

Following Cramer (p. 356) the basic model used to test for advertising-price interaction is a logarithmic first-difference model as follows:

(6a) $$d \ln q_i = a_i + b_{ii}\, d \ln p_i + c_{ii}\, d \ln A_i + d_i\, d\,(\ln p_i \cdot \ln A_i) + e_i\, d \ln X_i$$
$$+ \text{ shift variables}$$

where i indexes the four beverages in the non-alcoholic group (milk, juices, soft drinks, and coffee and tea), $X = \sum_{i=1}^{4} p_i\, q_i$ is group expenditure, and the shift variables include the prices of and advertising expenditures for the competing beverages in the group, all expressed as first differences in logarithms.

In this model, the own-price elasticities are given by:

(7) $$\eta_{ii} = b_{ii} + d_i \cdot \ln A_i^{\mathrm{o}}$$

which vary with the advertising levels in which they are evaluated. With the maintained hypothesis that $c_{ii} > 0$ (positive shift effect), there is a theoretical prejudice in favor of advertising making demand less price elastic. Hence, the coefficients d_i in general are expected to be positive (given that units are selected such that $\ln A_i^{\mathrm{o}} > 0$).

To examine robustness, three variants of (6) were estimated. The first variant is a levels version of (6a):

(6b) $$\ln q_i = a_i' + b_{ii}' \ln p_i + c_{ii}' \ln A_i + d_i' (\ln p_i \cdot \ln A_i) + e_i' \ln (X_i/P)$$
$$+ \text{ shift variables}$$

where the group expenditure variable X is deflated by Stones price index $\ln P = \sum_{i=1}^{4} w_i \ln p_i$ where $w_i = p_i\, q_i/X$ is group expenditure share. Equation (6b), which is motivated by Alston *et al*.'s analysis, is termed the "compensated double-log model." A basic difference between (6a) and (6b) is that the former includes a trend term via the intercept a_i.

The second variant in essence multiplies the dependent variable of (6a) by w_i to yield the "unrestricted Rotterdam" specification:

(6c) $$w_i\, d \ln q_i = \iota_i + \pi_{ii}\, d \ln p_i + \lambda_{ii}\, d \ln A_i + \gamma_i\, (d \ln p_i \cdot d \ln A_i) + \theta_i\, d \ln Q$$

$$+ \text{ shift variables}$$

where $d \ln Q = \sum_{i=1}^{4} w_i\, d \ln q_i$ is the Divisia volume index. In this specification the (compensated) own-price elasticities are given by:

(8) $$\eta_{ii}^* = (\pi_{ii} + \gamma_i \cdot d \ln A_i)/w_i,$$

which vary with the change in advertising but also budget shares. In estimation the parameters of (6c) are constrained to satisfy the adding-up, homogeneity, and symmetry conditions of economic theory.

The final variant is Theil's version of (6c) in which advertising elasticities are assumed to be proportional to price elasticities. This assumption leads to the "restricted Rotterdam" specification:

(6d) $$w_i\, d \ln q_i = \iota_i' + \sum_{j=1}^{4} \pi_{ij}'\, (d \ln p_j - \phi_j\, d \ln A_j) + \gamma_i'\, [d \ln p_i \cdot d \ln A_i - \phi_i\, (d \ln A_i)^2]$$

$$+ \theta_i'\, d \ln Q$$

where $\phi_j = \partial \ln (\partial u/\partial q_j)/\partial \ln A_j$ is the interpreted as "the elasticity of the marginal utility of good j with respect to advertising of good j" (Selvanathan, p. 216). The advantage of (6d) is that it reduces the number of advertising parameters that have to be estimated from n^2 to n, or from 16 to four in our system. Because the π_{ii}' and γ_i' parameters in (6d) have the same interpretation as their counterparts in (6c), own-price elasticities can be computed using (8). As with (6c), in estimation homogeneity and symmetry are imposed and adding-up is used to recover the parameters of the deleted equation.

Data and Estimation Procedures

The models were estimated using U.S. annual time series data for the period 1970-2000. The price and quantity data were obtained from government sources; the advertising data were obtained from private sources, chiefly *Ad $ Summary* published by Leading National Advertisers, Inc. A complete description of the data, including sources, is available in Kinnucan *et al*. (2001, pp. 24-28).

The equations were estimated as a system using Seemingly Unrelated Regressions. In the case of the Rotterdam models [(6c) and (6d)] one equation was dropped to avoid singularity in the variance-covariance matrix. As indicated, these equations were estimated with homogeneity and symmetry imposed, and adding-up was used to recover the coefficients from the dropped equation. In the unrestricted model (6c) the advertising coefficients satisfy (Selvanathan, p. 216):

$$\text{(9)} \qquad \sum_{j=1}^{4} \lambda_{ij} = 0, \qquad i = 1, 2, 3, 4$$

which is also imposed.

Results

Estimation results are satisfactory in the sense that the Durbin-Watson statistics across the four models show little evidence of serial correlation (table 1). The R^2s range from 0.88 to 0.99 in the levels model to between 0.36 and 0.80 in the first-difference models with little to choose between the Cramer and Rotterdam specifications. Overall, the models appear to do a better job of explaining juices and soft-drink demand than milk and coffee and tea demand, especially in the first-difference specifications. For ease of discussion, equations (6a) - (6d) will hereafter be referred to as Models A - D.

The estimated coefficients of the interaction terms in Models A - D along with the corresponding t-ratios are provided in table 2. Also provided in table 2 are the computed Wald statistics for the null hypothesis that the estimated interaction effects are jointly zero. The most striking aspect of the estimates is their sensitivity to model specification. In particular, Models A and C fail to reject the null hypothesis of no interaction effects whereas Model D rejects the null at the 5% level ($p = 0.041$) and model B rejects decisively ($p = 0.0001$). In other words, the compensated double-log (levels) model and the restricted Rotterdam models are supportive of the hypothesis that advertising has rotated the demand curves for non-alcoholic beverages in the United States whereas first-difference double log (Cramer) model and unrestricted Rotterdam models indicate the opposite..

Focusing on Models B and D, the hypothesis that advertising makes demand less price elastic is supported by Model D in that all of the estimated interaction effects are positive with the juice effect significant at the 1% level. In contrast, Model B provides ambiguous support for the hypothesis in that among the three significant coefficients only one has a positive sign. Combining results from the two models, it appears based on t-statistics that advertising made the demand for juices and coffee and tea less price elastic and the demand for milk and soft drinks more price elastic.

The foregoing conclusions rest on the assumption that the models showing significant interaction effects (B and D) are superior specifications of demand than the models showing non-significant effects (A and C). Since the models are non-nested in principle a J-test could be used to discriminate among them. Rather than formal tests, model adequacy is assessed informally via the reasonableness and significance of the own-price elasticities implied by the four models as reported in table 3. For milk, models A and B perform the best on this criterion, yielding estimates of the own-price elasticity of -0.08 and -0.22, respectively, although neither are significant at usual probability levels. For juices, models C and D perform best, yielding elasticities of -0.31 and -0.14, respectively. For soft drinks, models A and C perform best, yielding elasticities of -0.56 and -0.23, respectively. For coffee and tea models C and D perform best, yielding nearly identical elasticities of -0.22 and -0.23, respectively. Tallying the results, model C, then unrestricted Rotterdam, seems to have the edge, albeit slight.

Concluding Comments

This paper distinguishes rotation from shift effects of advertising on own-price demand elasticity. Four models are adopted to test the rotation effects in the U.S. non-alcoholic beverage market. Results are mixed in that the full Rotterdam and first difference double-log models fail to reject the null hypothesis of no rotation while the restricted Rotterdam and compensated double-log models indicate rejection. Rotation effects were found to be not robust to a change in model specification. This confirms Hauser and Wernerfelt's (1989) result that functional forms used to model advertising and price interactions influence conclusions about its direction. One reason for the ambiguous results may be multicollinearity problems associated with the unrestricted models. Still, our overall conclusion is that there is little solid evidence to suggest that generic advertising rotated the demand curves for non-alcoholic beverages in the United States.

Table 1. Summary Statistics from Estimated Beverage Demand Models, United Sates, 1970-2002 Annual Data

Model/Commodity	R^2	*D.W.*
Double-log First Differences (Model A):		
Milk	0.36	1.81
Juices	0.68	2.09
Soft Drinks	0.8	2.25
Coffee and Tea	0.65	1.96
Compensated Double-log Levels (Model B):		
Milk	0.99	1.91
Juices	0.91	2.17
Soft Drinks	0.99	1.77
Coffee and Tea	0.88	1.17
Unrestricted Rotterdam (Model C):		
Milk	0.38	2.24
Juices	0.65	2.03
Soft Drinks	0.62	1.34
Coffee and Tea	0.39	2.32
Restricted Rotterdam (Model D):		
Milk	0.4	1.78
Juices	0.66	2.27
Soft Drinks	0.63	1.79
Coffee and Tea	0.4	2.3

Table 2. Estimated Interaction Terms

Good	Model A	Model B	Model C	Model D
	(d_i)	(d_i')	(γ_i)	(γ_i')
Milk	0.006	-0.041	-0.014	0.002
	(0.34)[a]	(-3.31)	(-0.37)	(0.99)
Juices	0.057	0.017	0.092	0.334
	(0.38)	(0.18)	(0.67)	(2.26)
Soft Drinks	-0.129	-0.170	-0.062	0.158
	(-2.08)	(-3.07)	(-0.38)	(1.37)
Coffee & Tea	0.118	0.122	0.026	0.026
	(1.59)	(2.03)	(0.49)	(0.51)
Wald Statistic[b]	1.78	20.3	0.64	8.28
	(0.142)	(0.0001)	(0.888)	(0.041)

[a] Figures in parentheses are *t*-ratios.

[b] Tests the null hypothesis that the interaction terms are jointly zero. Figure in parentheses below statistic indicates significance level.

Table 3. Estimated Own-Price Elasticities for Non-Alcoholic Beverages Evaluated at 1970-2000 Sample Means

Good	Without Interaction Effect		With Interaction Effect	
	Model A	Model C	Model B	Model D
Milk	-0.084	-0.023	-0.215	0.0001
	(-1.10)[a]	(-0.57)	(-0.93)	(-0.15)
Juices	-0.382	-0.308	-0.140	-0.144
	(-1.59)	(-1.99)	(-0.37)	(-2.56)
Soft Drinks	-0.560	-0.095	-0.230	-0.072
	(-4.76)	(-1.34)	(-3.19)	(-1.80)
Coffee & Tea	-0.180	-0.219	-0.079	-0.234
	(-2.17)	(-3.08)	(-2.34)	(-3.52)

[a] Figures in parentheses are *t*-ratios. For models B and D *t*-ratios pertain to price coefficients only.

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