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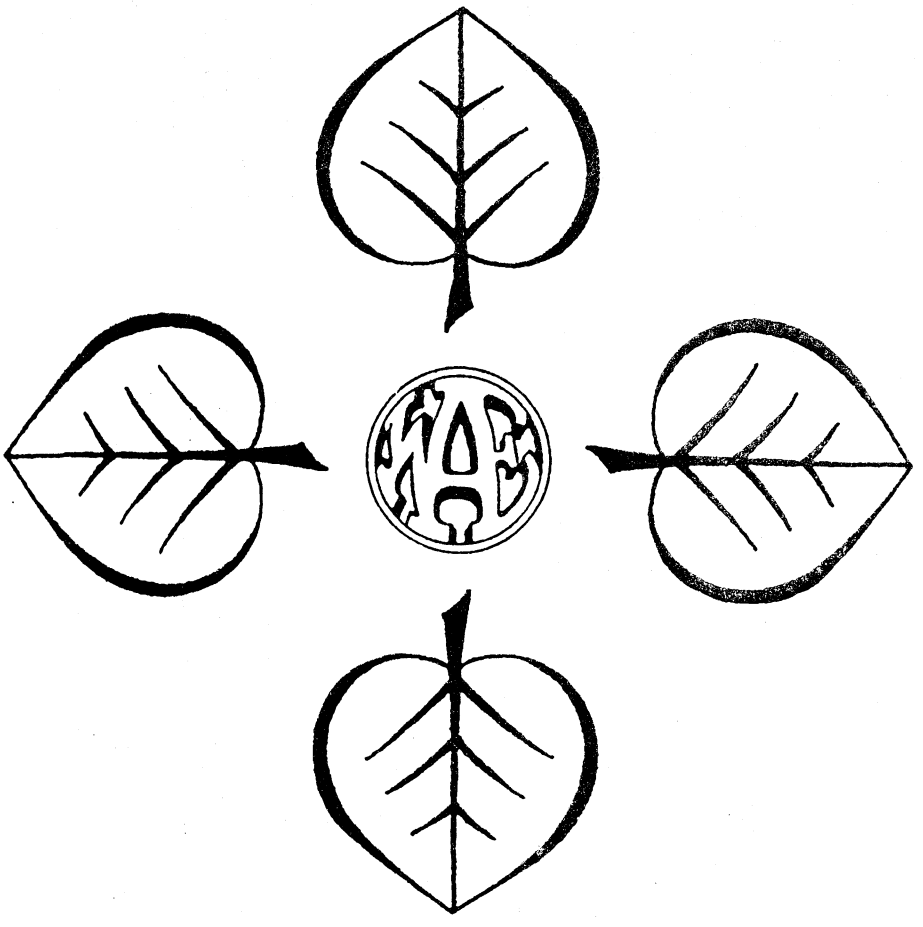

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A Factor Analysis Approach to Measuring the Effectiveness of Advertising

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Abstract

This study presents a latent variable factor analysis approach in measuring effectiveness of advertising in changing consumer demand. It is assumed that advertising affects latent consumers' perception of the advertised goods and through which influences their purchasing behavior. The consumer purchase and retail store advertising, which includes newspaper advertising, within store display, and point-of-purchase display of three fruit juices are studied in an extended Rotterdam model.

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A Factor Analysis Approach to Measuring the Effectiveness of Advertising

Economists have devoted considerable attention to measuring the effectiveness of advertising messages. The effectiveness of advertising have been analyzed both within the single (Kinnucan and Forker, Liu and Forker, Ward and Dixon) and system of demand equation framework (Duffy; Goddard and Amuah). The dynamic nature of advertising's effect on sales have been explored (Kinnucan and Forker, Liu and Forker, Ward and Dixon) and the potential simultaneity of feedback relationship that may exist between advertising and sales have been examined (Schmalensee). Moreover, once estimates of the effectiveness of advertising are obtained, optimal advertising rules, under various market arrangements (Dorfman and Steiner, Nerlove and Arrow) have been developed to guide decisions regarding the desired advertising intensity.

Recognizing that advertising level and quality are not readily quantified in attempting to measure the effectiveness of advertising, past studies have invariably employed producer advertising expenditures as a proxy for advertising messages. However, the use of proxies or variables measured with error within the standard regression framework renders parameter estimates biased and inconsistent (Theil 1979). Although models designed to handle latent variables have been widely used in some of the social sciences, they have not been commonly applied to economic data (Goldberger).

This study uses U.S. supermarket scanner check-out record sales data of orange juice, grapefruit juice, and apple juice to analyze the effectiveness of advertising by retail stores. An extended Rotterdam model, where latent variables representing advertising induced consumer perception to three juices are included, serves as the structural demand system. The model uses store display, newspaper advertising, and point of purchase display as indicators for the latent advertising message variable. Most prior research which has studied the effectiveness of fruit juice advertising has not considered advertising at the retail level. Instead, attention has been focused on advertising by producer groups and processors. However, according to industry sources, retailers in fact spend more on promotional activities than either processors or producer groups in the U.S. food sector.

Model Specification

The proper treatment of advertising in demand specifications remains a controversial issue. Some (e.g. Theil 1976) argue that since advertising works by changing consumer taste and preferences, thus affecting the marginal utilities of the goods in question, advertising should enter directly into the utility function and therefore should be treated in demand specifications in the same manner as price and income. Others (Nelson, Stigler and Becker, Kotowitz and Mathewson, Verma) suggest that advertising does not change taste and preferences, rather, advertising influences demand by changing consumer perception of the characteristics of the advertised good. They believe the hypothesis of "change-in-taste" implies "too much rationality" on the part of consumers. Consequently, advertising does not enter directly into the utility function, but enters into demand specifications through translating or scaling parameters.

This study follows the common approach (which both schools should agree, see Brown and Lee) of introducing consumer perception in demand specifications. It is argued that advertising affects consumer perception (real and/or fancied) of the advertised goods,

through which it influences consumer purchase behavior. Advertising induced consumer perception has both a taste and information interpretation in this specification. Regardless of whether it is defined as a shifter of consumer preference or information on shadow price, it affects consumer demand together with prices and income. The consumer demand functions in vector form are

(1) $q = q(p, m, \Xi)$,

where the q's are the quantities, p is a vector of prices, m is consumer expenditure, and Ξ represents consumer perceptions of the commodities. Multiplying both sides of the total differential of equation (1) by p_i/m and using $w_i = p_i q_i/m$, one obtains

(2) $w_i \text{dlog } q_i = \partial(p_i q_i/\partial m) \text{ dlog } m + \sum_{j=1}^{n}(p_i p_j/m)(\partial q_i/\partial p_j) \text{ dlog } p_j + \sum_{j=1}^{n}(p_i \Xi_j/m)(\partial q_i/\partial \Xi_j) \text{ dlog } \Xi_j$.

Using the Slutsky decomposition, the above equation can be simplified as

(3) $w_i \text{ dlog } q_i = \gamma_i \text{ dlog } Q + \sum_j \gamma_{ij} \text{ dlog } p_j + \sum_j \beta_{ij} \text{ dlog } \Xi_j$,

where $\text{dlog } Q = \sum w_i \text{dlog } q_i$ is the Divisia volume index; $\gamma_{ij} = w_i \epsilon^*_{ij}$ is the Slutsky coefficients. ϵ^*_{ij} is the compensated price elasticity; $\beta_{ij} = w_i \tau_{ij}$ and τ_{ij} are perception elasticities and can be further written as $-\sum_k \epsilon^*_{ik} v_{kj}$. v_{kj} is the elasticity of the marginal utility of good k with respect to perception of good j. Theil (1976) assumed v_{kj} to be diagonal, while Selvanathan gave no such restriction. Selvanathan's specification will be used in this research.

Equation (3), after adding an error term, is an extended Rotterdam model when the finite change version is taken and the coefficients are assumed constant. The adding-up condition requires that $\sum_i w_i \tau_{ij} = 0$, which means that the changes in advertising induced consumer perception will not increase total expenditure, they can only change the budget shares of the commodities. Barnett has shown that (3) is a first-order Taylor series expansion of a system of demands aggregated over a large number of consumers. In this sense, the model overcomes the aggregation problem. Using the Rational Random Behavior theorem, Theil (1975) proves that the group expenditure and Divisia volume index in (3) is independent of equation error terms so that there is no simultaneity error in the conditional demand system.

To minimize the measurement error, a latent variable structural modeling technique can be used for estimation. The model of equations (3) and (5) are then estimated by a structural factor analysis model which manifests each latent variable (also called factor) by several indicators. The structural factor analysis model is discussed following the next section.

Data Source

U.S. per capita demand for three juices are analyzed in this study--orange juice, grapefruit juice, and apple juice. The data are provided by A. C. Nielsen Research and are collected by a survey of retail grocery store scanner check-out records. The stores included in the survey have annual sales of more than four million dollars and account for more than 80% of the total juice retail volumes in the U.S. The data are weekly observations from November 14, 1987 to December 29, 1990 (a total of 160 observations) on consumer purchases, expenditures (from which average prices are also derived), and intensity of retail advertising activities. Three types of advertising activities employed by retail stores are included in this research--within store display (DSPL), newspaper advertising (A/B ADS), and point-of-purchase display (POP). These advertising variables measure the percentage of all commodity volume (ACV) sales where advertising activities were present. Information

about advertising sponsored by producers is not available, therefore it is not included in this research. Population estimates reported by the U.S. Department of Commerce were used to derive the per capita demand.

Factor Analysis Model and Empirical Specification

The structural factor analysis model can be specified by two parts, they are latent equations and measurement equations,

(4) $\eta = B\eta + \Gamma x + \zeta$,

(5) $y = \Lambda_y \eta + \epsilon$,

where, η ($m \times 1$) is the vector of latent variables; x ($n \times 1$) and y ($p \times 1$) are the vectors of observed variables; B, Γ, and Λ_y are coefficient matrices compatibly defined. The ϵ ($p \times 1$) are the errors of measurement for y. The measurement errors are uncorrelated with latent variables, η, and have an expected value of zero and variance Θ_ϵ. When Θ_ϵ are significant, indicator variables (y) are noisy and filtered to the latent variables (η) by the model.

In the fruit juice advertising problem we have three goods, three latent consumer perception variables, and each perception variable has three indicators. The latent and indicator variable vectors in this problem are defined as

(6) $\eta = [w_1\Delta\log(q_1)\ w_2\Delta\log(q_2)\ w_3\Delta\log(q_3)\ \Delta\log(\Xi_1)\ \Delta\log(\Xi_2)\ \Delta\log(\Xi_3)]'$,

(7) $y = [w_1\Delta\log(q_1)\ w_2\Delta\log(q_2)\ w_3\Delta\log(q_3)\ ID'_{1:3,1}\ ID'_{1:3,2}\ ID'_{1:3,3}]'$,

(8) $x = [\Delta\log(p_1)\ \Delta\log(p_2)\ \Delta\log(p_3)\ \sum_i w_i\Delta\log(q_i)]'$,

where $ID_{1:3,j}$ (j=1, 2, 3) is a vector of three indicators for orange juice (j=1), grapefruit juice (j=2), and apple juice (j=3), respectively. y has the dimension of 12×1. Note that the first three variables in η are observable variables.

The full model is given below for clarity:

(9) $w_i\ \Delta\log q_i = \gamma_i\ \Delta\log Q + \sum_{j=1}^{3} \gamma_{ij}\ \Delta\log p_j + \sum_{j=1}^{3} \beta_{ij}\ \Delta\log \Xi_j,\ \forall i$

(10) $ID_{kj} = \lambda_{kj}\ \Delta\log \Xi_j,\ \forall j$.

There are nine indicators, ID_{1j} represent DSPL for orange juice (j=1), grapefruit juice (j=2), and apple juice (j=3) respectively. ID_{2j} are A/B AD, and ID_{3j} are POP.

The structural factor analysis model is estimated by a multivariate moment estimator which minimizes the difference between the sample covariances and the covariances predicted by the model. (see Bollen for details).

Results

All conditional marginal shares (γ_i) and own-price Slutsky coefficients (γ_{ii}) are significantly different from zero at the one percent level (Table 1). Orange juice has the largest marginal share and grapefruit juice the smallest. All own price Slutsky coefficients have negative signs; the latent roots of the Slutsky coefficients matrix are zero and negative which indicate that the matrix is negative-semidefinite. All cross-product Slutsky coefficients are positive, indicating that these three juices are substitutes for each other. Price, expenditure and advertising perception elasticities are calculated but not presented. The results also show that the demand for grapefruit juice is price elastic while the demand for orange juice and apple juice are inelastic. Conditional expenditure elasticity of orange juice is greater than those of grapefruit juice and apple juice.

Results in table 1 show that orange juice demand is not significantly affected by advertising induced consumer perception of orange juice, but is negatively affected by consumer perception of apple juice and grapefruit juice. Results also show that consumers'

(favorable) perception of apple juice had negative effects on both orange juice and grapefruit juice demands. The significance of the latent advertising induced consumer perception variables in these demand equations show that retail promotional activities did affect consumer demand. The demand elasticities of grapefruit and apple juices with respect to consumer perceptions for these goods are positive and significant at the five percent level. However, the estimated elasticities for consumer perceptions are considerably smaller than price and expenditure elasticities.

The results presented in table 1 also show that all indicator coefficients (Λ) are significant. Both newspaper advertising (A/B ADS) and point-of-purchase (POP) display indices are significant in affecting consumer perceptions for all three juices. The validity of the within-store display (DSPL) indicator can not be judged since it is normalized to unity for all three juices to make the latent variable identifiable. The significance of the variances ($\Theta_{\epsilon 1}$, $\Theta_{\epsilon 2}$, $\Theta_{\epsilon 3}$) in the indicator equations implies that these indicators are imperfect and to use these variables directly in the demand system would introduce measurement error bias. The structural factor analysis model uses fewer advertising variables (in this case three latent advertising effectiveness variables) in the consumer demand model than the models using advertising indicators (in this case nine variables) as proxies, and thus reduces the chance of multicollinearity. The prediction power is also improved, the sum of the squares of the one period ahead prediction errors in the latent variable approach is less than ten percent of that when using the same data and advertising indicators as proxies directly.

The statistical results presented above show that retail promotion changed consumer demand for the three juices. To evaluate gains attributed to the advertising, a simulation is conducted to see how the demands change under different advertising scenarios. First, the three latent consumer perception variable indices are estimated using the EM methods (Dempster et al.) by treating the latent perception variables as missing values. The per capita consumption of the three juices is first predicted given the actual observations for all independent variables. Using the same model, sales are then predicted for a set of different advertising scenarios. The results indicate that consumer perception of apple juice, although significant in increasing its own demand, however, is overpowered by cross-product effects of consumer's perception of the two other juices. For instance, if there had been no retail advertising for all three juices, the orange juice and grapefruit juice demand would have decreased but that of apple juice would have slightly increased. The orange juice gained the most from advertising and apple juice the least.

Concluding Remarks

The using of latent variable methods and the arguments of the existence of a advertising induced latent consumer perception variable between retail (or producer) advertising and consumer demand is a promising approach to modeling advertising effectiveness. This paper, focusing on the effectiveness of retail level advertising and ignoring the possible existence of some national or generic promotions of these juices at the data period, is a study on limited advertising effort. However, as argued before, the retail (local) level is no less important than national campaign. This paper tries to shed some light and ignites interests in this area.

Although studies on advertising usually use lagged values of advertising indicator variables to incorporate the dynamic effects of advertising, this paper measures advertising activities in their current values. This has to do with the nature of the retail advertising,

where store displays are used to provides consumers with "on spot" stimulus or reminders for purchasing, the lag effect is minimum. Even for the newspaper advertising, weekly data would account for most of their effects (the validity of local newspaper coupons or discounts usually is less than a week). We conclude that, in contrast with other studies on national or generic promotions, the dynamic effect of retail advertising is a less significant problem in this model and a static model would suffice.

Table 1. Parameter Estimates For Latent Variable Structural Model
(Symmetry and Homogeneity Imposed)

	Orange Juice i=1		Grapefruit Juice i=2		Apple Juice i=3	
Variables (Param.)	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Conditional Slutsky Coefficients						
$\Delta Log(p_1)$ (γ_{i1})	-0.1785	0.0513	0.0589	0.0169	0.1196	0.0446
$\Delta Log(p_2)$ (γ_{i2})			-0.0970	0.0208	0.0381	0.0523
$\Delta Log(p_3)$ (γ_{i3})					-0.1577	0.0524
Conditional Marginal Shares						
$\sum_i w_i \Delta log(q_i)$ (γ_i)	0.7906	0.0185	0.0568	0.0061	0.1526	0.0161
Conditional Perception Coefficients						
$\Delta log(\Xi_{oj})$ (β_{i1})	0.0135	0.0126	-0.0009	0.0008	-0.0025	0.0032
$\Delta log(\Xi_{gj})$ (β_{i2})	-0.0030	0.0046	0.0359	0.0015	-0.0030	0.0228
$\Delta log(\Xi_{aj})$ (β_{i3})	-0.0105	0.0042	-0.0350	0.0014	0.0055	0.0285
Demand Residual Standard Errors						
Ψ	0.0041	0.0005	0.0013	0.0002	0.0013	0.0002
Indicator Coefficients						
DSPL (Λ_{i1})	1.000		1.000		1.0000	
A/D ADS (Λ_{i2})	2.3695	0.7916	1.8435	0.4838	2.1097	0.2978
POP (Λ_{i3})	1.1294	0.1550	0.9181	0.1332	1.4217	0.1643
Indicator residual Variances						
Θ_{e1}	0.1372	0.0221	0.1418	0.0227	0.2047	0.0303
Θ_{e2}	0.8072	0.0944	0.4888	0.0617	0.4559	0.0658
Θ_{e3}	-0.0561	0.0549	-0.0438	0.1133	0.1759	0.0478

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