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Optimal Choice of Generic Milk Advertising Expenditures by Media Outlet

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The largest portion of dairy and milk checkoff funds is spent on generic fluid milk advertising. These funds are distributed among four distinct media outlets—television, radio, print, and outdoor. Spending too little on one media outlet or too much on another constitutes a missed opportunity to garner higher returns. Using 1984–93 data, this study compares historical advertising expenditures in each media outlet to the advertising expenditure decision of an optimal control model. Results show profits would have increased if funds had been reallocated from television to radio, print, and outdoor media outlets.

Key words: generic fluid milk advertising, milk, optimal control

Introduction

Allocating funds to the generic promotion of milk and dairy products is an important decision-making process: 200 million checkoff dollars are distributed annually among promotion activities which include investments in nutrition research, consumer education, new product development, and generic advertising (Kaiser et al.). Generic advertising receives the largest portion of the production checkoff and is the focus of this study. The advertising dollars are distributed among four distinct media outlets—television, radio, print, and outdoor. Spending too little on one media outlet or too much on another constitutes a missed opportunity to garner higher returns. Little attention has been focused on the media allocation aspect of generic milk advertising. Yet, for our 1984–93 study period, it can be shown that a reallocation of expenditures would have strengthened milk demand and improved profitability.

Research pertaining to the effectiveness of milk advertising includes Thompson and Eiler; Kinnucan (1986); Kinnucan and Forker; Kaiser et al.; and Wohlegenant and Clary. These studies have shown that dairy advertising has a significant impact on fluid milk consumption. For instance, by regressing per capita fluid milk demand on monthly advertising expenditures and other important variables, Thompson and Eiler found a positive and significant advertising coefficient. Kinnucan (1986) reported similar results using a framework involving advertising "goodwill." Kinnucan and Forker investigated the seasonal pattern of advertising effectiveness and found seasonal goodwill elasticities

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follow milk demand, peaking in spring and declining over summer. Each of these studies focused on advertising impacts for a single product (fluid milk) within a single market. Multiple-product studies include Kaiser et al., who considered U.S. farm-to-wholesale and wholesale-to-retail linkages of advertising for fluid milk, cheese, butter, and frozen dairy products. Similarly, Wohlegenant and Clary's national model studied advertising effectiveness with respect to fluid milk and manufactured dairy products.

Researchers also have compared advertising expenditures in different locations. Goddard and McCutcheon investigated the optimal fluid advertising expenditure within Ontario and Quebec individually, but not between the two markets. In contrast, Liu and Forker (1990) examined generic fluid milk advertising expenditures among various markets in New York state. The authors concluded that a reallocation of expenditures among markets would have been beneficial. An additional contribution of Liu and Forker was placing the advertising allocation decision in an optimal control framework rather than an ad hoc simulation, as done in most of the previous studies. Liu and Forker's model was particularly relevant to the current study as it involved a full-fledged optimization procedure.

In addition to optimizing over product form and/or market areas, expenditures may be optimally allocated among media outlets. Since there are many different ways to convey an advertising message, the media mix generating the greatest returns must be identified. While none of the aforementioned studies have considered the media allocation issue, one recent exception is an investigation by Kinnucan and Thomas. They determined the impact of media allocation decisions on catfish producer welfare and found, surprisingly, that electronic (television and radio) advertising was not as profitable as print advertising. With regard to the dairy industry, to our knowledge, the only media allocation study was performed by Capps and Schmitz, who used simulation to disentangle the impact of radio versus television advertising for a Texas milk marketing order. Clearly, there is a need to explore the allocation decision for media outlets other than television and radio. Further, it is possible to cast the media allocation problem in an optimal control framework, as did Liu and Forker (1990). While Liu and Forker addressed the allocation issue among market areas, the current study focuses on media outlets.

Conceptual Framework

There are several ways to model media expenditures within an optimal control framework. For example, Nerlove and Arrow's capital theoretic approach considered advertising as an investment in a firm's goodwill, while Vidale and Wolfe's earlier framework viewed advertising as a method of capturing market potential. Within the context of diffusion, Gould extended the previous framework to allow for interaction between captured and uncaptured portions of the market. A review of this theoretical literature can be found in Liu and Forker (1989).

The above theoretical models are not readily applicable to the dairy industry. As pointed out by Liu and Forker (1990), these theoretical models assume the firm controls either the output price or quantity. Clearly, this assumption is not valid for the dairy promotion unit. In the present study, the promotion unit influences the demand for milk through generic advertising, and then dairy farmers react to the resulting market condition when making subsequent supply decisions. Specifically, our model is comprised of three parts: (*a*) a retail fluid milk demand equation expressing quantity as a function of advertising expenditures on various media outlets and other demand determinants; (*b*) a blend price equation, which depends on market conditions;[1] and (*c*) a farm milk supply equation, which depends, in part, on the expected blend price. The objective of the promotion unit is to maximize the discounted net revenue stream from farm milk sales where the control variables are advertising expenditures for each media outlet.

Retail Fluid Demand Equation

Retail fluid milk demand is a function of current and lagged advertising expenditures, prices, income, and other factors. The demand relationship may be represented as:

$$D_{t+1} = \Phi(\mathbf{A}_{t+1}, D_t \,|\, \mathbf{A}_{t-k}, k \geq 0, Z_{t+1}), \tag{1}$$

where D_{t+1} is the retail demand of milk in time period $t+1$, and $\mathbf{A}_{t+1}$ is a vector of advertising expenditures in media outlets with elements $A_{i,t+1}$, $i \in$ {outdoor, print, radio, television}. The demand at $t+1$ is a function of current advertising ($\mathbf{A}_{t+1}$) and lagged sales (D_t), conditional on the advertising expenditure levels of the previous periods ($\mathbf{A}_{t-k}$). The lagged demand accounts for consumer habit, while the lagged expenditures capture the carryover effect on demand of previous advertising. Clearly, the duration of the carryover (k) is an empirical issue, explored in the estimation portion of this study. The variable Z_{t+1} captures contemporaneous impacts of other variables, such as retail price and income, treated as exogenous to the model.[2]

Farm Milk Supply Equation

The supply of farm milk depends on the expected blend price, input prices, and production capacity. Assuming that farmers have a naive price expectation, the expected price for $t+1$ is simply the observed blend price in t (p_t^b). The farm milk supply equation can be specified as:

$$S_{t+1} = f(p_t^b, S_t, W_t), \tag{2.1}$$

where S_{t+1} is the farm supply of milk in period $t+1$, and the lagged supply captures farm capacity constraints. The variable W_t represents the impacts on supply of such exogenous factors as input prices.

The blend price is endogenous. Advertising affects retail fluid milk demand, which in turn changes the blend price via changes in fluid utilization (given the predetermined farm milk supply). This model assumes that a single milk marketing order exists for all

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[1] Dairy farmers receive a blend price based on milk marketing order class prices, weighted by the utilization rates of fluid milk and manufactured dairy products.

[2] One might argue that treating the retail milk price as exogenous would result in overstating the impact of advertising on demand because of an upward-sloping retail supply curve. However, for the industry we are investigating, the above problem may not be a concern due to the pricing system of the federal milk marketing order: milk used for fluid purposes commands a premium of about $2 per cwt. Since only about 40% of the milk is used for fluid purposes, the fluid milk market should be able to attract as much milk as its demand can absorb without retail price increases.

producers under which fluid milk processors buy raw milk paying the basic formula price (P_t) plus an exogenously determined Class I milk differential (δ_t). Thus, the blend price is:

$$p_t^b = \delta_t \frac{D_t}{S_t} + P_t. \tag{2.2}$$

Given (2.2), the supply transition in (2.1) can be expressed as:

$$S_{t+1} = \Psi(D_t, S_t \mid \delta_t, P_t, W_t). \tag{2.3}$$

Inequality Constraints

The optimization model includes the following inequality constraints. First, fluid milk sales cannot exceed farm milk supply:

$$D_t \leq S_t. \tag{3.1}$$

Also, advertising expenditures may not exceed budgetary constraints. Specifically, spending at time t across all media outlets ($\Sigma_i A_{i,t}$) is restricted to be no greater than actual (i.e., historical) total advertising expenditures at that time, $\overline{A}_t$:[3]

$$\sum_i A_{i,t} \leq \overline{A}_t. \tag{3.2}$$

Finally, the following nonnegativity constraints are imposed:

$$D_t \geq 0, \ \ S_t \geq 0, \ \text{and} \ \ A_{i,t} \geq 0. \tag{3.3}$$

Objective Function

Subject to equations (1), (2.1), (2.2), (3.1), (3.2), and (3.3), the objective of the promotion unit is to maximize the discounted net revenue stream for a selected period of time ($t = 1, 2, \ldots, T$) by choosing advertising expenditures for the ith media outlet $\{A_{i,t}: t = 1, \ldots, T\}$ so as to drive the state variables, fluid milk sales $\{D_t: t = 1, \ldots, T\}$ and farm milk supply $\{S_t: t = 1, \ldots, T\}$, to the optimal path.[4] We represent this mathematically as:

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[3] As discussed above, advertising is not the sole promotion activity from which the agency must choose (e.g., new product development, consumer education, nutrition research). Constraining total media expenditures to be no greater than the observed expenditures assumes the promotion unit has already made the optimal choice among the more broadly defined promotion activities. Results from our sensitivity analysis (available from the authors upon request) indicate that increasing the advertising budget does not qualitatively change the conclusion.

[4] Obviously, this objective function reflects the perspective of the promotion unit. A reasonable alternative would be to maximize the net profit of producers, which accounts for the costs of farm production as well. The two formulations, however, do not yield different insights because of minimal supply response from advertising (Liu and Forker 1988).

$$H = \sum_{t=1}^{T-1} \rho^t \left\{ p_t^b S_t - \sum_i A_{i,t} \right\} + \rho^T V(D_T, S_T), \tag{4}$$

where $\rho \equiv (1+r)^{-1}$ and r is the interest rate; $V(D_T, S_T)$ is a salvage term including terminal cash flow and the terminal value of the state variables D_T and S_T.

A Solution Insight

The conceptual framework presented in the previous section is a dynamic, nonlinear-nonautonomous optimization problem with multiple state variables. The nonlinearity results from Φ and Ψ, while nonautonomy corresponds to the time-varying nature of the exogenous factors $\{\delta_t\}$, $\{P_t\}$, $\{Z_t\}$, and $\{W_t\}$. While a complete analytical solution for the problem is difficult to obtain, insight into the solution can be gained by examining the necessary conditions for optimality and deriving the steady-state solution. Following Liu and Forker (1990), necessary conditions of the solution require:

$$\rho \lambda_{t+1} \Phi_{A_i} = 1, \quad \forall\, i \in \{\text{outdoor, print, radio, television}\}, \tag{5}$$

where Φ_{A_i} is the marginal impact of the ith media outlet on fluid milk demand, ρ is the appropriate discount rate, and λ_{t+1} is the current-value adjoint variable of milk demand. The optimality condition (5) dictates that the last dollar spent on the ith media outlet equals the discounted shadow value of additional fluid sales from advertising. Further, (5) implies that the marginal benefit of advertising must be equalized across all media outlets. Following Liu and Forker (1990), the steady state can be expressed as:

$$r + \Phi_D = \Phi_{A_i} \left[\delta + \frac{P \Psi_D}{r - \Psi_S} \right], \quad \forall\, i \in \{\text{outdoor, print, radio, television}\}, \tag{6}$$

where $\Phi_D = \partial\Phi/\partial D$, $\Psi_D = \partial\Psi/\partial D$, $\Psi_S = \partial\Psi/\partial S$, and δ, P, A_i, D, and S are the steady-state values of $\{\delta_t\}$, $\{P_t\}$, $\{A_{i,t}\}$, $\{D_t\}$, and $\{S_t\}$, respectively. The steady-state solution in (6) dictates that the marginal opportunity costs of each media outlet equal its marginal benefit. The marginal opportunity costs include the time cost (r) and the cost associated with decay in fluid milk demand (Φ_D). The marginal benefit of the ith media outlet includes additional revenue from increased fluid milk sales ($\delta\Phi_{A_i}$) and additional revenue from the subsequent farm milk supply response ($P\Psi_D\Phi_{A_i}$). However, the revenue generated by the supply response is discounted by the time cost (r) and the farm capacity depreciation rate ($-\Psi_S$).

The Econometric Model

The fluid milk demand in (1) and the farm supply in (2.1) are estimated econometrically. The estimation is based on U.S. quarterly data from the first quarter of 1975 through the final quarter of 1993.

Fluid Milk Demand Estimation

In the estimation, the demand for fluid milk is specified on a per capita basis (D_{t+1}/POP_{t+1}). Independent variables include lagged per capita retail demand (D_t/POP_t) to capture habit formation, seasonal dummy variables (*SEAS*1, *SEAS*2, *SEAS*3) to account for demand seasonality, the retail price index for fluid milk (*PMILK*), the retail price index for nonalcoholic beverages (*PBEV*) as a proxy for milk substitutes, per capita income (INC_t/POP_t), and a trend (*TREND*) to account for changes in consumer tastes and preferences. The fluid milk quantity data are collected from the U.S. Department of Agriculture's (USDA's) *Dairy Situation and Outlook Report* and measured on a milk fat equivalent basis. The price variables and income are deflated by the consumer price index and are taken from the U.S. Department of Labor/Bureau of Labor Statistics *Consumer Price Index* and *Employment and Earnings* publication series.

The media expenditures are measured in thousand dollars, deflated by the media cost index and obtained from Leading National Advertisers, Inc. The fluid milk advertising expenditures are grouped into four media outlets (A_i) and are denoted as *PRINT*, *RADIO*, *TV*, and *OUTDOOR*.[5] While local and state promotion programs existed throughout the study period, the National Dairy Board did not begin advertising fluid milk on television until 1984. Thus, in addition to the *TV* variable, an interaction term for the National Dairy Board program is included (i.e., $NDB * TV$). As suggested by Ward and Dixon, the coordination of a national campaign has increased fluid milk consumption, more so than a simple increase in local and state advertising expenditures.

Media outlet variables are specified as second-order polynomial distributed lag functions of the current and previous four quarters' expenditures. Polynomial distributed lags are used to reduce the number of parameters to be estimated by imposing a specific prior on the lag structure. In this study, lag functions are specified with and without the two endpoint restrictions. Imposing the two endpoint restrictions means the instantaneous effect of advertising on milk demand is negligible and the effect completely dies out after the final period of lag specification. On the other hand, specifying no endpoint restrictions allows for an instantaneous impact on milk demand that may continue beyond the final period. It has been suggested by previous authors (e.g., Capps and Moen; Lee and Brown) that restricting lag structures may unduly influence the estimated advertising coefficients in a certain fashion. This econometric issue is examined below, while its impact on the robustness of the policy conclusion is considered in the optimization section.

All the variables in the fluid milk demand equation are in logarithmic form except the seasonal dummies. The equation is estimated using an instrumental variable procedure to account for the potential endogeneity of the retail milk price variable (*PMILK*). Specifically, the retail milk price is regressed on its one-period lag and a trend variable, as well as a first-order autoregressive error term to correct for autocorrelation. The predicted retail milk price is then used as the price instrument for the own-price in the demand estimation. Results of the estimation are presented in table 1.

Fluid demand equation A is estimated with the two endpoint restrictions, while fluid demand equation B is estimated without these restrictions. First consider fluid demand

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[5] As pointed out by a reviewer, it is possible that the generic advertising of manufactured dairy products could impact fluid milk demand. Generic cheese advertising expenditures have been included in the demand estimation as an explanatory variable. However, this variable was subsequently omitted because the coefficient was not significant.

Table 1. Retail Fluid Demand Estimation Results

Dependent Variable: $\ln(D_{t+1}/POP_{t+1})$	Fluid Demand Equation A (2 endpoint restrictions)		Fluid Demand Equation B (no endpoint restrictions)	
Variable	Coefficient	t-Statistic	Coefficient	t-Statistic
Constant	-1.3050	-4.160**	-1.3455	-4.072**
*SEAS*1	-0.0334	-4.894**	-0.0342	-4.954**
*SEAS*2	-0.0750	-13.290**	-0.0745	-11.570**
*SEAS*3	-0.0508	-14.630**	-0.0490	-10.696**
$\ln(D_t/POP_t)$	0.3558	3.151**	0.3169	2.718**
$\ln(PMILK_t)$	-0.0420	-0.599	-0.0996	-1.332
$\ln(INC_t/POP_t)$	0.1948	2.951**	0.2124	3.163**
$\ln(PBEV_t)$	0.0564	2.978**	0.0652	3.188**
$\ln(TREND)$	-0.0587	-3.881**	-0.0745	-4.623**
$\ln(PRINT)$[a]	0.0023	1.940**	0.0025	1.990**
$\ln(TV)$[a]	0.0106	2.047**	0.0108	1.987**
$\ln(RADIO)$[a]	0.0009	1.646*	0.0012	1.999**
$\ln(OUTDOOR)$[a]	0.0045	1.107	0.0087	1.960**
$\ln(NDB * TV)$[a]	0.0018	1.358	0.0023	1.714**
Durbin-*h*	0.262986		-3.7700	
Adj. R^2	0.9487		0.9636	

Note: Single and double asterisks (*) denote significance at the 90% and 95% confidence levels, respectively.

[a] The advertising variables (*PRINT*, *TV*, *RADIO*, and *OUTDOOR*) are specified as second-order polynomial distributed lag functions of current and previous four quarters' expenditures. The values reported in this table are long-run elasticities; period-by-period lags are shown in table 2.

equation A. The coefficients associated with the seasonal dummy variables (*SEAS*1, *SEAS*2, *SEAS*3) are significant, as is the coefficient for the lagged dependent variable (D_t/POP_t). As expected, the coefficients on *INC* / *POP* and *PBEV* are positive and significant, suggesting fluid milk is a normal good and that nonalcoholic beverages are substitutes for fluid milk. The estimated *TREND* coefficient is negative and statistically significant, reflecting a steady decline in consumer preference for milk. The negative sign on *PMILK* is expected; however, the coefficient is not statistically significant—which is also found in previous empirical studies (e.g., Kaiser and Reberte; Kinnucan 1987; Kinnucan and Forker).

The advertising coefficients reported in table 1 are long-run elasticities obtained by summing up the current as well as lagged media coefficients. In fluid demand equation A, the media coefficients are all positive. Further, the *PRINT* and *TV* variables are significantly different from zero at the 95% confidence level, and *RADIO* is significant at the 90% confidence level. However, the *OUTDOOR* coefficient is not significant at the conventional levels.[6] The robustness of the policy implications drawn from these estimates might be influenced by the estimation uncertainty associated with the

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[6] As pointed out by a reviewer, the insignificant *OUTDOOR* coefficient may be due to the fact that little has been spent in this media outlet. The historical outdoor spending level may be below the minimum threshold to impact fluid milk demand.

Table 2. Restricted and Unrestricted Values for Polynomial Advertising Lags

	Fluid Demand Equation A (2 endpoint restrictions)		Fluid Demand Equation B (no endpoint restrictions)	
Variable	Elasticity	*t*-Statistic	Elasticity	*t*-Statistic
$\ln(PRINT_{t+1})$	0.00033	1.93970**	0.00116	2.17016**
$\ln(PRINT_{t})$	0.00054	1.93970**	0.00031	0.92631
$\ln(PRINT_{t-1})$	0.00060	1.93970**	-0.00002	-0.05827
$\ln(PRINT_{t-2})$	0.00054	1.93970**	0.00017	0.47830
$\ln(PRINT_{t-3})$	0.00033	1.93970**	0.00089	1.54851*
$\ln(TV_{t+1})$	0.00151	2.04653**	0.00390	1.17838
$\ln(TV_{t})$	0.00242	2.04653**	-0.00104	-0.60627
$\ln(TV_{t-1})$	0.00272	2.04653**	-0.00191	-0.82008
$\ln(TV_{t-2})$	0.00242	2.04653**	0.00130	0.79687
$\ln(TV_{t-3})$	0.00151	2.04653**	0.00858	2.59108**
$\ln(RADIO_{t+1})$	0.00013	1.64618*	0.00053	1.75938**
$\ln(RADIO_{t})$	0.00021	1.64618*	0.00046	2.41175**
$\ln(RADIO_{t-1})$	0.00024	1.64618*	0.00031	1.58191*
$\ln(RADIO_{t-2})$	0.00021	1.64618*	0.00009	0.53568
$\ln(RADIO_{t-3})$	0.00013	1.64618*	-0.00021	-0.84253
$\ln(OUTDOOR_{t+1})$	0.00064	1.10682	0.00343	1.86196**
$\ln(OUTDOOR_{t})$	0.00103	1.10682	0.00252	2.26425**
$\ln(OUTDOOR_{t-1})$	0.00116	1.10682	0.00167	1.35995*
$\ln(OUTDOOR_{t-2})$	0.00103	1.10682	0.00090	0.86916
$\ln(OUTDOOR_{t-3})$	0.00064	1.10682	0.00020	0.11922

Note: Single and double asterisks (*) denote significance at the 90% and 95% confidence levels, respectively.

OUTDOOR coefficient and will be examined in the optimization section. The interaction dummy variable *NDB*∗*TV* is positive, but significant only at the 80% confidence level.

With few exceptions, results of fluid demand equation B (estimated with no endpoint restrictions) are similar to those of fluid demand equation A (table 1). The own milk price coefficient is twice as large as it was in equation A, but still not significant at conventional confidence levels. While the advertising coefficients for *PRINT*, *TV*, and *RADIO* in equation B are similar in magnitude to equation A, the *OUTDOOR* coefficient is now twice as large and highly significant. The interaction dummy variable between *NDB* and *TV* is also highly significant in equation B. Based on the adjusted R^2s, both demand equations have about the same explanatory power. However, the Durbin-*h* statistic indicates that fluid demand equation B suffers the problem of autocorrelation. Although attempts were made to correct for autocorrelation, they were unsuccessful.

As noted previously, the media coefficients in table 1 are long-run elasticities. The advertising coefficients pertaining to individual periods are reported in table 2 for fluid demand equations A and B (with and without endpoint restrictions, respectively). It is evident that endpoint restrictions impose a very specific lag structure on each of the media variables. Consider the *PRINT* variable for "restricted" fluid demand equation A. The *PRINT* elasticity follows an inverted "V" pattern; it begins in period $t+1$ at 0.00033, increases in period t to 0.00054, peaks in period $t-1$ at 0.00060, and then declines thereafter. Notice also that the lag structure is symmetric. The advertising coefficient in period $t+1$ is the same as in period $t-3$; likewise, the coefficients for periods t and $t-2$ are identical. Clearly, the estimated lag pattern is a result of the second-order polynomial lag specification with both endpoint restrictions imposed. An intuitive explanation for this lag structure (gradual increase, peak, and then decline) is that, once consumers observe the advertising message, it takes time for them to absorb the information content and then act upon it. However, the information eventually "dies out."

In contrast, consider "unrestricted" fluid demand equation B in table 2, in which there are no endpoint restrictions. Note that the *PRINT* elasticity declines from period $t+1$ until period $t-1$, and then steadily increases to period $t-3$. While not imposing that the lag structure be symmetric, the empirical result of a "V" lag pattern is not as intuitive as the inverted "V" in equation A. A similar "V" pattern is also found for the *TV* coefficients. However, the "V" pattern is not observed for the *RADIO* and *OUTDOOR* coefficients. Instead, the coefficients for these two media outlets are largest in period $t+1$, and steadily decline thereafter. This pattern is intuitive and is consistent with the inverted "V" pattern found for equation A, if one ignores the delayed impact of advertising. The coefficients in unrestricted equation B are, in general, not significant as often as those in restricted equation A. Both versions of the fluid demand equation will be entertained in the optimal control of media expenditures. In this manner, the robustness of the policy recommendation may be ascertained.

Farm Milk Supply Estimation

The supply equation is in double-logarithmic form except for the intercept dummy variables. Farm milk supply (S_{t+1}) is regressed on lagged farm supply for three periods (S_t, S_{t-1}, S_{t-2}),[7] an output/input price ratio [i.e., the lagged blend price (p_t^b) divided by the lagged price for 16% protein feed ($PFEED_t$)], the deflated lagged slaughter cow price ($PKCOW_t$), two dummy variables [set to one for January 1984 through June 1985 to represent the Milk Diversion Program (MDP), and set to one for April 1986 through September 1987 to represent the Dairy Termination Program (DTP), respectively], a trend variable, and three seasonal dummy variables. The farm milk supply variable is defined as farm milk production minus on-farm use, and the blend price variable is the U.S. all-milk price. Time-series data for the above variables are obtained from the USDA *Dairy Situation and Outlook Report.* Results for the farm milk supply estimation are found in table 3.

The output-input price ratio ($p_t^b/PFEED_t$) captures the price effect on supply, and is positive and significant. The lagged dependent variables capture farm capacity constraints, and all three lags are statistically significant. While one of the lagged

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[7] A four-lag specification also was considered; the estimation results are nearly identical to the three-lag formulation, which is chosen for parsimonious reasons. The results from the optimal control model are qualitatively and quantitatively the same for both lag specifications.

Table 3. Farm Milk Supply Estimation Results

Dependent Variable: $\ln(S_{t+1})$

Variable	Coefficient	t-Statistic
Constant	1.409	2.765**
*SEAS*1	0.007	0.451
*SEAS*2	0.058	2.992**
*SEAS*3	-0.013	-0.621
$\ln(S_t)$	0.669	3.605**
$\ln(S_{t-1})$	-0.454	-2.497**
$\ln(S_{t-2})$	0.387	2.940**
$\ln(p_t^b/PFEED_t)$	0.068	2.049**
$\ln(PKCOW_t)$	-0.058	-2.530**
$\ln(TREND)$	0.037	1.941**
MDP	-0.022	-2.439**
DTP	-0.027	-1.976**

Durbin-h = 0.1617; Adj. R^2 = 0.9644

Notes: Double asterisks (**) denote significance at the 95% confidence level; t-statistics are computed using White's correction for heteroskedasticity.

coefficients (S_{t-1}) is negative, the equation does satisfy the stability condition.[8] The slaughter cow price accounts for the opportunity costs of maintaining a dairy herd and, as expected, its coefficient is negative and statistically significant. As expected, the policy dummies *MDP* and *DTP* are negative and significantly different from zero. Finally, *TREND* captures the impact of technology on dairy production and is positive and significant.

The Optimization Results

The estimated retail milk demand equation is adapted to the form of (1) by collapsing shifters into Z_{t+1}, excluding lagged milk demand and media expenditures. Similarly, the farm milk supply equation is adapted to the form of (2.1) by collapsing all supply determinants into W_t except for farm milk price (p_t^b) and lagged supply (S_t, S_{t-1}, S_{t-2}). It is then possible to maximize the objective function (4) subject to the state equations (1) and (2.1), the blend price formula (2.2), and the constraints (3.1)–(3.3). The interest rate r [recall $\rho \equiv (1+r)^{-1}$] is defined as 25% of the effective annual rate index. We use 6.155% as the annual rate index, since it was the average rate on six-month Treasury Bills between 1985–95. The optimization problem is solved for the period beginning in the first quarter of 1984 through the final quarter of 1993.[9]

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[8] When the supply equation is written as a first-order system, i.e., $\mathbf{y}_t = \mathbf{a}_t + \mathbf{A}\mathbf{y}_{t-1}$, where the vector $\mathbf{y}_t = (S_{t+1}, S_t, S_{t-1})^T$, the three roots of **A** lie within the unit circle—indicating the system is stable. The negative coefficient for S_{t-1} in the farm supply equation indicates a cyclical process of approximately 3.86 quarters.

[9] Note that the terminal value function $V(\cdot)$ in (4) includes cash flow in the last period ($p_T^b * S_T$) and the terminal values of the state variables D_T and S_T. To account for the terminal values of D_T and S_T, we allow the optimal control program to iterate an additional 40 periods (10 years) with the restriction that there are no advertising expenditures in those periods.

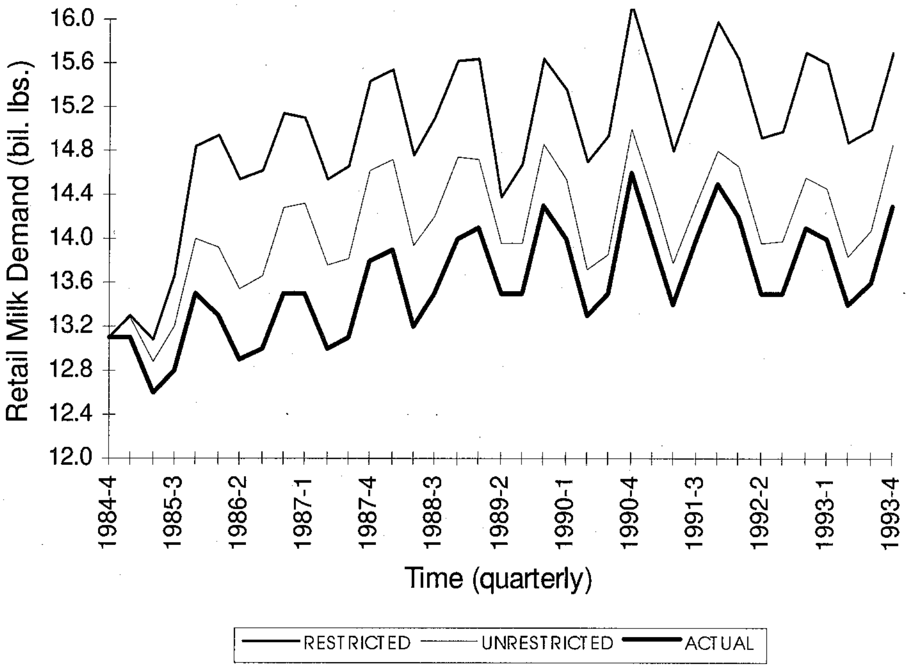

Figure 1. Actual versus simulated demand with optimal media allocation, 1984–93

The results of the optimization suggest there are important benefits to redistributing media expenditures. Using restricted fluid demand equation A, the optimal media mix increases the discounted profit in (4) by $950 million ($95 million per year) over the simulation period. While this represents only a small portion of the revenue stream in (4), this additional profit can be obtained virtually cost-free. We obtain a similar qualitative result when using unrestricted fluid demand equation B, but profits increase by only $427 million ($43 million per year). Increased profits are due to an increase in fluid milk demand. Figure 1 compares the actual quarterly retail fluid demand quantity (denoted "actual") with that simulated under the optimal media allocation using either fluid demand equation A with two endpoint restrictions (denoted "restricted"), or fluid demand equation B without endpoint restrictions (denoted "unrestricted"). The unrestricted quantities lie between the actual and the restricted quantities in figure 1.[10]

What does the optimal media allocation look like? In absolute terms, one would expect the most effective media outlet to have the largest share of expenditures. The econometric results clearly indicate that television has the largest advertising coefficient. As a result, television has the largest share of expenditures relative to print, radio, and outdoor. However, due to diminishing marginal returns, overspending on television is

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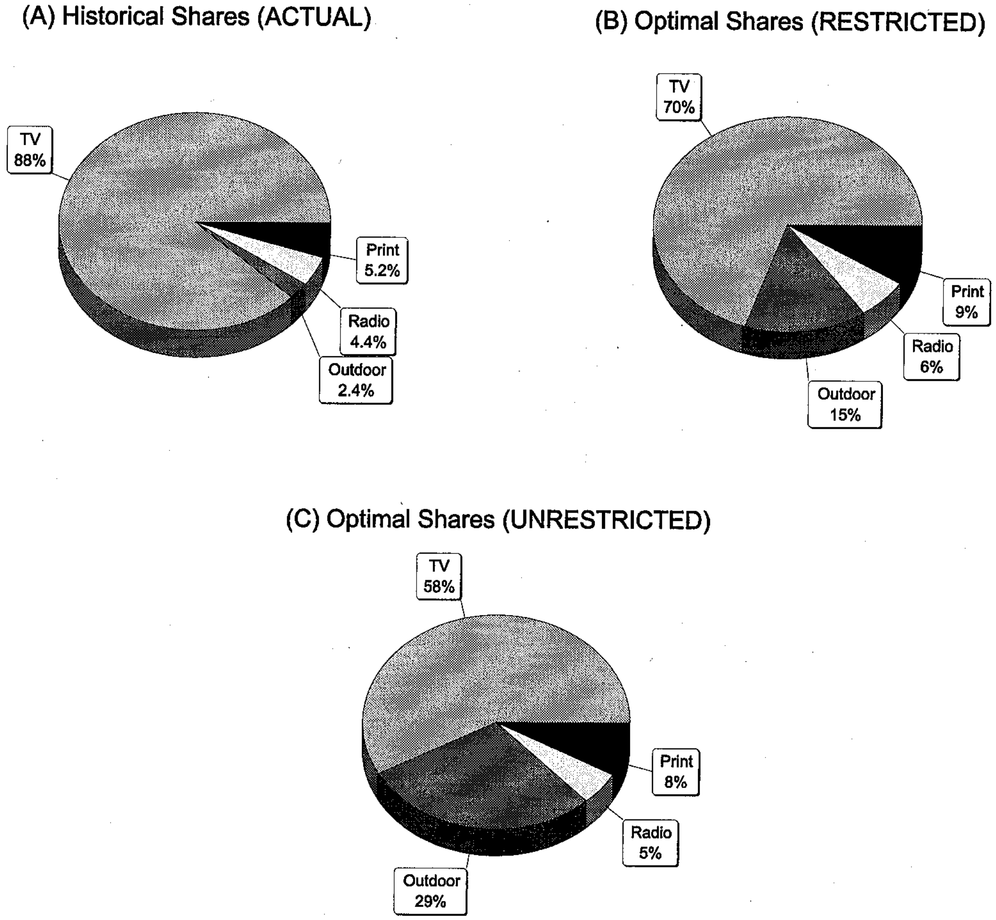
[10] The result that the simulated demand under the restricted model (fluid demand equation A) is greater than under the unrestricted model (fluid demand equation B) may be counterintuitive, because the estimated coefficients of *TV*, *RADIO*, *PRINT*, and *OUTDOOR* are smaller in the restricted model. This can be explained by noting that the effect of lagged fluid milk demand is greater in the restricted model than in the unrestricted model.



(A) Historical Shares (ACTUAL)

(B) Optimal Shares (RESTRICTED)

(C) Optimal Shares (UNRESTRICTED)

Figure 2. Percentage of total media expenditures by type: Actual versus optimal, 1984–93

possible, which would reduce profitability. To improve profitability, funds should then be diverted from television to the media outlet with the greatest marginal benefit. The optimality principle dictates that the marginal benefit must be equal for each media outlet, as illustrated by equation (5).

The three pie charts in figure 2 show a comparison of the actual media allocation with the optimal allocation under restricted fluid demand equation A and unrestricted fluid demand equation B. In the actual media allocation (pie chart A), an average of 88% of quarterly expenditures was allocated to television between 1984–93. Yet, the optimal television share is reduced to roughly 70% in the restricted model (i.e., equation A with two endpoint restrictions, pie chart B), while increases are shown for print (from 5% to 9%), radio (from 4% to 6%), and outdoor (from 2% to 15%) advertising expenditures. With the unrestricted model (i.e., equation B with no endpoint restrictions, pie chart C), television is reduced even further to 58%, while increases occur for print (from 5% to 8%), radio (from 4% to 5%), and outdoor (from 2% to 29%) advertising expenditures.

Regardless of the endpoint restriction on the advertising distributive lag structure, the qualitative results suggest that a reallocation away from television to other media types was in order during the 1984–93 simulation period. This finding is consistent with Kinnucan and Thomas' study of catfish media allocation.

A caveat applies to the analysis of the restricted model. Recall that the advertising elasticities for the *OUTDOOR* coefficients are not significantly different from zero in fluid demand equation A. To ascertain the robustness of the policy conclusion, the optimization was repeated with *OUTDOOR* elasticities set equal to zero. The resulting optimal allocation is 80% for television, rather than the 70% reported for the restricted model (pie chart B of figure 2). While the estimation uncertainty surrounding the outdoor coefficient affects the optimal level of spending, it is never the case that television should receive 88% of the advertising budget as actually observed. Sensitivity analysis is also applied to *TELEVISION*, *RADIO*, and *PRINT* by adding and subtracting the respective standard deviation to the estimated media coefficients. The adjustments are made for one media outlet at a time and the optimization repeated. Adding one standard deviation to the coefficient of a media type should increase its share of advertising expenditures. Yet, the policy conclusion is not reversed by these sensitivity analyses; television should not have received as large a share of the expenditures as was actually allocated.[11]

Conclusion

This analysis examines how dairy advertising expenditures are allocated among four different media outlets—television, print, radio, and outdoor. The problem is cast within an optimal control framework which includes a retail fluid milk demand equation, a blend price equation, and a farm milk supply equation. The model is used to allocate funds to those media outlets to maximize the discounted revenue of farm milk sales net of advertising expenditures over a period of time. Care is taken in the estimation and optimization to ensure the robustness of the policy conclusion.

For the simulation period 1984–93, the results of the optimization suggest that reallocating expenditures among media outlets would have resulted in increased profits for dairy farmers. Specifically, the results show an increase in discounted profit of $95 million per year under a demand specification with two endpoint restrictions and $43 million under a demand specification without endpoint restrictions. While representing only a small percentage of the total revenue, these additional profits could have been obtained nearly cost-free. The optimal allocation with two endpoint restrictions suggests that the share of advertising expenditures devoted to television be reduced from 88% to 70%, while expenditure increases are indicated for print (from 5% to 9%), radio (from 4% to 6%), and outdoor (from 2% to 15%) advertising. Alternatively, if one posits a demand model of no endpoint restriction, television is reduced from 88% to 58%, while print, radio, and outdoor expenditures increase from 5% to 8%, 4% to 5%, and 2% to 29%, respectively. These results suggest that print, radio, and outdoor advertising are more cost effective at the margin than was envisioned by the promotion unit.

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[11] For example, by adding one standard deviation to the *TV* coefficient, the optimal solution dictates 85% for television, 4% for radio, and 11% for print. By adding one standard deviation to the *RADIO* coefficient, the optimal solution dictates 77% for television, 9% for radio, and 14% for print. Finally, by adding one standard deviation to the *PRINT* coefficient, the optimal solution dictates 75% for television, 5% for radio, and 20% for print.

While the policy direction is that television expenditures should have been reduced in favor of other media outlets, several caveats apply. First, this analysis evaluates the aggregate performance of advertising campaigns over a period of 10 years without regard to the effectiveness of a specific campaign being conducted during a specific subperiod. It is entirely possible that television advertising expenditures were optimal for a specific campaign, while they were overused for other campaigns on average. Further research on specific campaigns over the study period might be useful in resolving this question. Second, the study considers the optimal mix of media expenditures for the period 1984–93, and the results may not necessarily be applicable to the future. This would be particularly true if a more effective television campaign is developed. In fact, the "Got Milk?" campaign, which was not part of the time period in this study, may in fact be a case in point. Third, it is possible that the dairy promotion unit receives price discounts for high-volume media purchases. In that event, shifting funds from television to other media outlets might compromise these discounts. Obviously, the validity of this issue can be best assessed by the program managers themselves. Finally, the model assumes a national milk marketing order. In truth, there are regional differences in both advertising responses and utilization percentages of dairy products. Further analysis is needed to address these issues.

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