A Nonparametric Test of Advertising's Effectiveness

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May 15, 2001

Abstract

Nonparametric demand analysis uses axioms of revealed preference to test a data set for compatibility with the hypothesis of stable preferences. Previous applications have tested for the presence of structural change using this approach. This paper shows how to include demand shifters such as advertising in the analysis. It is shown that the implied results for changes in tastes depend on restrictions on advertising's effects.

Selected Paper, American Agricultural Economics Association, Chicago, IL, August 2001.

Keywords: advertising, promotion, revealed preference, nonparametric demand analysis, meat demand

JEL Classification Numbers: D12, Q11.

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Evaluating the returns to generic promotion of agricultural products has interested agricultural economists for some time. Such promotion is controversial, as evidenced by several recent legal challenges, including the Wileman case decided by the U.S. Supreme Court in 1996 and, more recently, the United Foods case, heard by the Court in April. The mandatory nature of check-off schemes to fund generic advertising is its most contentious aspect, but there is also disagreement about the effects of the advertising itself. Crespi and Sexton provide an up-to-date assessment of the legal setting for marketing orders and generic promotion. As they suggest, generic promotion seems likely to remain controversial.

Measurement of the effects of promotion is also somewhat controversial. Piggott et al. likened the problem to the more general problem of measuring structural change in demand. In both cases, tests of hypotheses of interest—no structural change or no demand shifts due to promotion—are conditional on maintained hypotheses concerning functional form, assumptions about the simultaneity of prices and expenditure, separability, aggregation, etc. In particular, a lot of attention has been paid to the sensitivity of results to decisions concerning the functional form of demand equations and those concerning how the variables meant to capture the demand shift are included in the model.

These problems are not all unique to demand analysis, although an impression that at least some demand analysts pay more attention to these problems than is common in other fields of research is probably not incorrect. A solution to the problems of functional form and uncertainty about simultaneity is provided by nonparametric demand analysis using revealed preference. Because the method does not involve regression, such assumptions are not part of the analysis. Varian (1982) marked a renewal of interest in the approach, which dates back to Samuelson, Houthakker, and Afriat. Studies applying the method to consumption data include Landsburg; Chalfant and Alston; Burton; Sakong and Hayes; Cortez and Senauer; and Chalfant and Zhang. For examples using production data, see Varian (1984), Chavas and Cox (1988, 1994), Cox and Chavas, and others.

To date, no one has modeled the effects of promotion on demand using a nonparametric approach. A pessimistic version of the preceding statement is that every result in the literature concerning the effects of promotion has been conditional on an ad hoc assumption concerning functional form. Moreover, the typical study uses only one functional form, so there is little formal evidence concerning how seriously one should take the problem of the functional form as maintained hypothesis. Simulations pertaining to the more general area of structural change in Alston and Chalfant (1991) are not encouraging regarding the likely fragility of the measured effects of promotion.

The nonparametric approach is not a panacea, a point made most recently by Chalfant and Zhang. It should probably be viewed as a supplement to more familiar parametric methods. For instance, its power is unknown, it does not lend itself naturally to a statistical interpretation, with such familiar summary measures as confidence intervals for effects of interest, and, like the parametric approach, it is conditional on the data-related modeling assumptions concerning separability and aggregation. If nothing else, however, the nonparametric approach serves to indicate whether the effect being measured is a strong characteristic of the data, or whether it will be necessary to make assumptions concerning functional form and perhaps elasticities in order to measure the effect of interest.

The above points will be elaborated as the paper progresses. The following section serves as a brief review of some particular methods in the nonparametric area, beginning with the simplest: are the data consistent with revealed preference axioms? Additional constraints will then be placed on the data to measure demand responses to promotion. The paper then turns to an analysis involving promotion.

Testing for Stable Preferences

Testing a data set for structural change is simple. Suppose there are T observations on price and (per capita) quantity vectors for the n goods of interest. The n goods must either exhaust the budget or represent a group for which weak separability is assumed. The data could have been generated by a well-behaved, stable utility function, provided that the data set contains no violations of Houthakker's Strong Axiom of Revealed Preference (SARP). This is easily checked.

Let the matrix $C = \{\{C_{ij}\}\} \quad i, j = 1, \ldots, T$, where $C_{ij} = p_i \cdot q_j$. C_{ij} thus represents the cost of the time j quantity vector at time i prices. A violation of the Weak Axiom of Revealed Preference (WARP) then has occurred if both $C_{ii} > C_{ij}$ and $C_{jj} > C_{ji}$. A violation of WARP implies either irrational behavior or a preference reversal. Finding no violations of WARP can be interpreted as a finding of stable preferences. Since WARP does not rule out violations of transitivity, consistency with the Strong Axiom of Revealed Preference (SARP) or the Generalized Axiom of Revealed Preference (GARP) in Varian (1982) is the more complete test of whether observed data are consistent with the maximization of a stable, well-behaved utility function.

A violation of SARP is of the form $C_{ii} > C_{ij}$, $C_{jj} > C_{jk}$, and $C_{kk} > C_{ki}$. The first inequality implies $q_i \mathcal{R} q_j$, the second $q_j \mathcal{R} q_k$, and the third $q_k \mathcal{R} q_i$. Any number of observations can comprise the SARP violation: for instance, $C_{ii} > C_{ij}$, $C_{jj} > C_{jk}$, and $C_{kk} > C_{kl}$, and $C_{ll} > C_{li}$ are jointly inconsistent with well-behaved preferences. If no such violations of transitivity are found, then the data can be rationalized, as Varian (1982) termed consistency with revealed preference. This means that there is some utility function that, when maximized subject to the budget constraints implied by the observed prices and expenditure, would have yielded the observed consumption bundles each period.

Since Landsburg, there has been concern over the power of such a test. Will data sets that are *not* consistent with stable preferences still appear consistent, because the test is not powerful? Perhaps data that were generated from one set of changing preferences will appear to be consistent with a different, stable set of preferences. Varian (1982) noted that, in the typical case of expenditures growing over time, each year's bundle will be revealed preferred to all previously observed bundles, and preference changes are unlikely to be detected, due to the fact that they are confounded with the observed effects of expenditure growth.

Chalfant and Alston suggested a procedure by which observed quantities could be adjusted for expenditure growth, yielding a set of adjusted quantities that could then be tested for stability. They noted that this procedure would increase the power of the test, to the extent that the information imposed on expenditure elasticities was correct. Sakong and Hayes advanced this approach considerably, by recasting WARP as a comparison of *compensated* demands. Their procedure permits ranges of expenditure elasticities to be incorporated, unlike the single-point approach of Chalfant and Alston, and places the compensation in the context of the underlying substitution and income effects from consumer theory. The next section of the paper elaborates.

Incorporating Information Concerning Elasticities

We begin with equation (1) from Sakong and Hayes (p. 271), modified to include a vector of r advertising variables, A. The demand for good i ($i = 1, 2, \ldots, n$) is

$$x_i = f_i(p, y, A, ct)$$

where p is a vector of n prices, y is income, and ct is taste. It follows that

$$\Delta x_i = \sum_{j=1}^{n} \frac{\partial f_i}{\partial p_j} \Delta p_j + \frac{\partial f_i}{\partial y} \Delta y + \sum_{k=1}^{r} \frac{\partial f_i}{\partial A_k} \Delta A_k + ctc_i$$

where

$$ctc_i = \frac{\partial f_i}{\partial ct} \Delta ct.$$

The meaning of the above equation is that the observed changes in x_i consumption should be explainable by price changes, changes in expenditures on the group of goods, and the effects of advertising of good i or related goods; any residual change is attributed to the effects of a change in the taste variable.

The Slutsky equation allows substitution for $\partial f_i / \partial p_j$:

$$\frac{\partial f_i}{\partial p_j} = \left. \frac{\partial f_i}{\partial p_j} \right|_{U_0} - \frac{\partial f_i}{\partial y} x_j.$$

Thus

$$\begin{aligned}
\Delta x_i &= \sum_{j=1}^{n} \left.\frac{\partial f_i}{\partial p_j}\right|_{U_0} \Delta p_j + \frac{\partial f_i}{\partial y}\left[\Delta y - \sum_{j=1}^{n} x_j \Delta p_j\right] + \sum_{k=1}^{r} \frac{\partial f_i}{\partial A_k}\Delta A_k + ctc_i \\
&= \sum_{j=1}^{n} \left.\frac{\partial f_i}{\partial p_j}\right|_{U_0} \Delta p_j + \frac{\partial f_i}{\partial y}\cdot\frac{y}{x_i}\frac{x_i}{y}\left[\Delta y - \sum_{j=1}^{n} x_j \Delta p_j\right] + \sum_{k=1}^{r} \frac{\partial f_i}{\partial A_k}\frac{A_k}{x_i}\frac{x_i}{A_k}\Delta A_k + ctc_i \\
&= \sum_{j=1}^{n} \left.\frac{\partial f_i}{\partial p_j}\right|_{U_0} \Delta p_j + a\cdot\frac{x_i}{y}\eta_{i,y} + \sum_{k=1}^{r} \eta_{i,A_k}\frac{x_i}{A_k}\Delta A_k + ctc_i
\end{aligned}$$

where

$$a = \Delta y - \sum_{j=1}^{n} x_j \Delta p_j,$$

$\eta_{i,y}$ is the income elasticity of demand for good i, and η_{i,A_k} is the elasticity of demand for good i with respect to advertising variable A_k.

Now add a time subscript:

$$x_{i,t} - x_{i,t-1} = \sum_{j=1}^{n} \left.\frac{\partial f_i}{\partial p_j}\right|_{U_{t-1}} \Delta p_j + a_t\frac{x_{i,t}}{y_t}\eta_{i,y}^{t} + \sum_{k=1}^{r} \eta_{i,A_k}^{t}\frac{x_{i,t}}{y_t}\Delta A_k$$

(ignoring ctc_i) which implies that

$$x_{i,t-1} + \sum_{j=1}^{n} \left.\frac{\partial f_i}{\partial p_j}\right|_{U_{t-1}} \Delta p_j = x_{i,t} - a_t\frac{x_{i,t}}{y_t}\eta_{i,y}^{t} - \sum_{k=1}^{r} \eta_{i,A_k}^{t}\frac{x_{i,t}}{A_{k,t}}\Delta A_k$$

As in Sakong and Hayes, the left-hand side is the sum of the previous quantity demanded and the substitution effect of price changes from $t-1$ to t, and is by definition the time t compensated demand x_t^*. The right-hand side is the time t quantity demanded, minus the changes in that quantity that can be attributed to changes in expenditure and to changes in advertising.

In the simplest version of nonparametric demand analysis, revealed preference axioms are checked with observed quantities. Those quantities change from observation to observation as *all* exogenous variables change; nothing is held constant. An observed change in consumption patterns may be equally consistent with some taste change, on the one hand, or with stable preferences and a particular collection of expenditure elasticities and income effects, on the other. Chalfant and Alston noted that the stable preferences that rationalize a particular data set may also imply expenditure elasticities that are implausible. There is no way to tell if that is the case with the standard WARP or SARP conditions, but by working with the compensated demands derived above, it is possible to find the set of expenditure elasticities and taste changes needed to rationalize the data. When the data can be rationalized with no taste changes and plausible expenditure elasticities, it would not be possible to reject the stable preferences hypothesis. Alternatively, if constraints on the allowable set of expenditure elasticities—ruling out inferior goods, for instance—require taste changes, then a test of stability that incorporates prior information about expenditure elasticities has been achieved. In this manner, the Sakong and Hayes method permits testing for stable preferences, or estimating taste changes, while imposing whatever prior information is desired by the researcher.

All that is necessary is to construct a series of compensated demands, and then to check what Sakong and Hayes (p. 272) termed the *convexity conditions.* Their method can be implemented with linear programming, solving the problem

$$\min b' CTC$$

subject to

$$P_t \cdot (Q_t^* - CTC_t) \leq P_t \cdot (Q_s^* - CTC_s)$$

for all t and s;

$$\sum w_i^t \eta_{iy}^t = 1 \quad \forall\ t;$$

and

$$\eta_{iy}^t \geq 0 \ \ \forall\ i, t.$$

The vector b consists of constant weights and CTC is the vector of taste changes, across all goods and observations. The choice variables are the elasticities and the taste changes. This problem replaces the standard test for compatibility with revealed preference, as in Varian or Chalfant and Alston, with a test for whether the data are consistent simultaneously with stable preferences and expenditure elasticities that are all positive, thereby ruling out inferior goods, and that satisfy Engel aggregation. If $CTC = 0$ can be achieved, then the data can be rationalized, subject to the constraints imposed, by picking the right elasticities. Otherwise, the program finds the smallest set of taste changes that will make the data set consistent with stable preferences.

Our modification of their method introduces advertising; we simply add the term for advertising effects to the formula for the compensated demand, and then impose whatever constraints on the signs and magnitudes of advertising elasticities as may seem appropriate. To the extent that quantities consumed shift from advertising, not expenditures, that shift can thus also be accounted for, instead of attributing the apparent demand shift to a taste change of unknown origin. Any remaining variation in quantities, not explained by expenditures and advertising, then is attributed to the effects of taste changes.

Comparison to Regression

The discussion above could have been applied to a regression model. By including variables thought to help explain the dependent variable, one hopes to attribute less and less remaining unexplained variation to error. The taste changes that are produced by the nonparametric method can be thought of as being analogous to the errors from a regression model—they each are departures from the demand model fully explaining quantities—but there is an important difference. Adding advertising, for instance, to the typical demand equation to be estimated using parametric regression techniques, we would likely treat its coefficient as a constant. While there is no particular reason to believe that the effects of an incremental unit of advertising effort or expenditure has the same effect on demand for every observation, the constant parameters assumption is inherent in most parametric methods. Certainly, a Chow test for structural change is one way to accommodate this, but most demand applications do not relax the constant parameters assumption beyond some specific break point, or maybe do so only by interacting variables such as advertising with a trend or some other measure of parameter shift. In the limit, treating the parameters of the model as random, and shifting at every data point, a perfect explanation of the data can always be achieved. This is analogous to adding a dummy variable for one specific observation—as is well known, that dummy variable's coefficient is the residual for that observation when the intercept is held constant. An observation-specific dummy is equivalent to allowing the intercept to shift for that one observation, and a perfect prediction is guaranteed.

Naturally, some compromise must be reached, somewhere between the choice of making a few parameters constant for all observations, in which case, structural change seems very likely with most time-series data, or letting the parameters change so often that any series of data can be explained away by parameter shifts. Certainly, without multiple observations in the same time period, there is a fundamental lack of identification between taste change and one-time parameter shifts.

Our nonparametric method has the same problem. Suppose that, without advertising, there appeared to be a taste change needed to reconcile one observation with the stable preferences hypothesis, as captured by the conditions comprising SARP. With advertising, we can simply solve for the advertising elasticity needed to equate what appeared to be a taste change with the effect of advertising. At another inconsistent observation, that same advertising elasticity would likely need to take on a different value to reconcile the second data point. In a model where advertising elasticities must be constant, such a reconciliation is not possible. In a nonparametric model that simply finds particular values to solve for the zero taste-change condition, it is easy to achieve. Thus, in the empirical work below, we illustrate how the implied taste changes vary from zero to something closer to what a parametric model might find, by limiting the ranges over which particular elasticities are allowed to vary.

Before turning to the application, one more note of interpretation might be useful. In all parametric demand models but the double-log, elasticities are *not* constant across observations. For instance, in the Almost Ideal demand system, the formulas for price and income elasticities show that the magnitudes of elasticities depend on budget shares.

Whether predicted or actual shares are used to evaluate elasticity formulas, anything that changes shares—prices or income, certainly—will change elasticities. It is the underlying coefficients, such as the coefficient on real income in the share equation, that are constant. Elasticities thus change in a pre-determined way, according to the formulas. This point is made in a very compelling demonstration, in another context, by Despotakis. Thus, nonparametric demand analysis, which at first seems very ad hoc and overly flexible, since elasticities change at every data point, is not that much different than parametric models in that property. The elasticities from parametric models change at every data point in ways that are not usually given much thought, but the nonparametric approach facilitates adding some structure, if desired, to the pattern of implied elasticities.

In the discussion that follows, we show the effects of constraining first expenditure elasticities, following Sakong and Hayes, and then also advertising elasticities. From the above discussion, it is clear that we will find a relationship between the role of advertising in shifting tastes, and estimated taste changes. The particular magnitudes of elasticities and taste changes, across various sets of assumptions, cannot be understood without the empirical framework.

Data Description

The empirical illustration uses data from Piggott et al. for Australian meat demand. The data are quarterly (1970:II to 1988:IV), consisting of the prices and per capita quantities of beef, lamb, pork, and chicken. Two variables representing advertising effort are available: expenditures on advertising by the Australian Pork Corporation (APC), on behalf of pork producers, and expenditures on advertising by the Australian Meat and Livestock Corporation (AMLC), for beef and lamb. These advertising expenditure data are from Ball and Dewbre. They were computed as the sum of real advertising expenditures in each of three media (television, radio, and print), calculated as nominal advertising expenditure deflated by a price index for each medium, and are expressed in thousands of dollars.

The data show a shift away from beef consumption beginning in the late 1970s, and a steady increase in chicken consumption over time. Consumption of lamb and pork was relatively stable over the same period. Figures 1a and 1b show the trends in meat consumption and prices, respectively, over the sample period. Figure 1c shows the advertising activity by AMLC and APC, which began in 1977 and increased substantially over the sample period.

It is not surprising that it is hard to separate the effects of prices, advertising, and taste change. Advertising activity began during a period of rising prices of beef, lamb, and pork. In spite of the perceived instability, Piggott et al. (p. 269) found that these data were consistent with GARP, implying that a stable, well-behaved utility function can rationalize the data. This means that there is some set of per capita demand relationships that generate the observed quantities as functions of prices and expenditures alone. There is no need to include a trend variable, quarterly dummies to capture seasonality, or advertising. As noted by Piggott et al. and discussed above, such a finding does not mean that a particular functional form will appear to be stable, or that the implied elasticities are at all plausible. It also does not mean that, when a parametric model is tried or restrictions on elasticities are imposed, there will not be evidence of some structural change, including some effects of advertising. It means only that finding significant structural change or advertising effects depends crucially on the other restrictions imposed on the model. Since we often do have prior beliefs about likely ranges of elasticities, imposing that information may well be a preferred approach, relative to the ad hoc adoption of a particular functional form (Chalfant and Alston). We turn now to exploring the effects of such restrictions on elasticities.

Empirical Results

We began by estimating taste changes using the Sakong and Hayes problem described above. Advertising was not included, and expenditure elasticities were required only to be non-negative, and to satisfy adding-up. The estimated expenditure elasticities turned out to be fairly large for some observations. Expenditure elasticities for pork ranged between 0 and 6.314, for lamb between 0 and 7.21, and for chicken between 0 and 9.061. Expenditure elasticities for beef were more reasonable (between 0 and 2.25), although still high relative to previous estimates and common sense. This suggests that we were understating the degree of taste change, and imposing unduly mild restrictions on expenditure elasticities.

The next program we ran incorporated restrictions on the allowable ranges for estimated expenditure elasticities. We restricted the expenditure elasticity for beef to be between 1.042 and 1.369, the expenditure elasticity for pork to be between 0.462 and 1.374, and the expenditure elasticities for lamb and chicken to be between 0.392 and 1.374. These are more plausible ranges, taken from published estimates for other data sets.

The effects of the further restrictions can be seen by comparing Figures 2 and 3. Figure 2 shows our estimated per capita taste changes, in kilograms, relative to the first data point, the second quarter of 1970. Our program finds the amounts to *add* to observed quantities to reconcile them with stable preferences. Thus, a negative taste change means that the observed quantity was *too large*; we had to add a negative number to reconcile the data. There are few instances where a taste change of either sign was needed. Certainly, the results do not detect a continuous trend away from beef during the 1970s and 1980s, as was suggested by some previous studies, but a small shift toward beef during the early 1970s, and then very small shifts both to and from beef during the 1980s. The results for other meats are comparable.

Figure 3 shows the new series of estimated taste changes after restricting expenditure elasticities. The magnitudes are considerably larger, and suggest a shift away from beef in the mid-1970s, and again at a few data points in the 1980s. These results reinforce the argument made by Sakong and Hayes; restrictions on expenditure elasticities lead to larger taste changes. As long as the restrictions we have imposed are plausible, Figure 3 represents a more plausible story than does Figure 2.

We added advertising effects to the model in Figure 4. The only restriction that advertising elasticities must satisfy for Figure 4 is adding-up. We kept the same restrictions on expenditure elasticities as were incorporated in Figure 3. As predicted, without restricting the advertising elasticities, the implied taste changes are zero, as soon as there were positive amounts of advertising observed in the data. As we discussed above, this is because the advertising elasticities can be adjusted arbitrarily to produce exactly the shift in quanitities previously attributed to taste changes. As was the case with the expenditure elasticities in

Figure 2, the estimated advertising elasticities themselves are naturally fairly unstable and not necessarily plausible.

Advertising elasticities for APC ranged between -0.74 and 0.828 for beef, -2.875 and 1.097 for pork, -0.911 and 1.489 for lamb, and between -1.9 and 3.353 for chicken. Clearly, these are not plausible ranges; not even the signs remain stable throughout the sample period. Similarly, elasticities for AMLC ranged between -0.158 and 1.22 for beef, -2.7 and 19.57 for pork, -12.32 and 1.152 for lamb, and between -14.93 and 2.99 for chicken.[1]

We conclude with Figure 5, which restricts the advertising elasticities. We chose a fairly simple restriction: the elasticities with respect to APC advertising must all be between 0 and 0.01. As can be seen in Figure 5, it is no longer possible for the program to explain away all of the taste changes using the advertising shifters. Although the estimated taste changes are small, there now are some non-zero values after advertising began. Eleven instances of taste changes are found; there are seven observations for which the beef quantity must be adjusted and four observations for which pork must be adjusted.

Conclusion

This paper introduced a method for incorporating advertising or other demand shifters into nonparametric demand analysis. The method extends previous work by Sakong and Hayes that permitted imposing prior beliefs about elasticities by making it possible to introduce similar prior beliefs about advertising elasticities. Indeed, this paper demonstrated that, without such prior beliefs, there will never be an estimated taste change when any demand

[1] Similar results were found when we replaced the contemporaneous advertising variable with the current value plus four lags.

shifter, such as advertising, can be used to explain away the apparent taste changes.

More work is clearly needed to determine plausible restrictions on advertising elasticities. While prior beliefs about advertising effects come from parametric studies, it is essential to place restrictions on elasticities in the nonparametric approach.

A further area of improvement for data sets such as this one is in modeling seasonality. We did not attempt to correct for seasonal variation in quantities consumed, although using quarterly data leaves us with more variation to be explained than in the typical time-series application with annual data. It may be that incorporating corrections for seasonality, if it is significant in a particular data set, will lead to more precise estimates of the effects of advertising and taste changes.

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Figure 1: Australian Meat Consumption Data

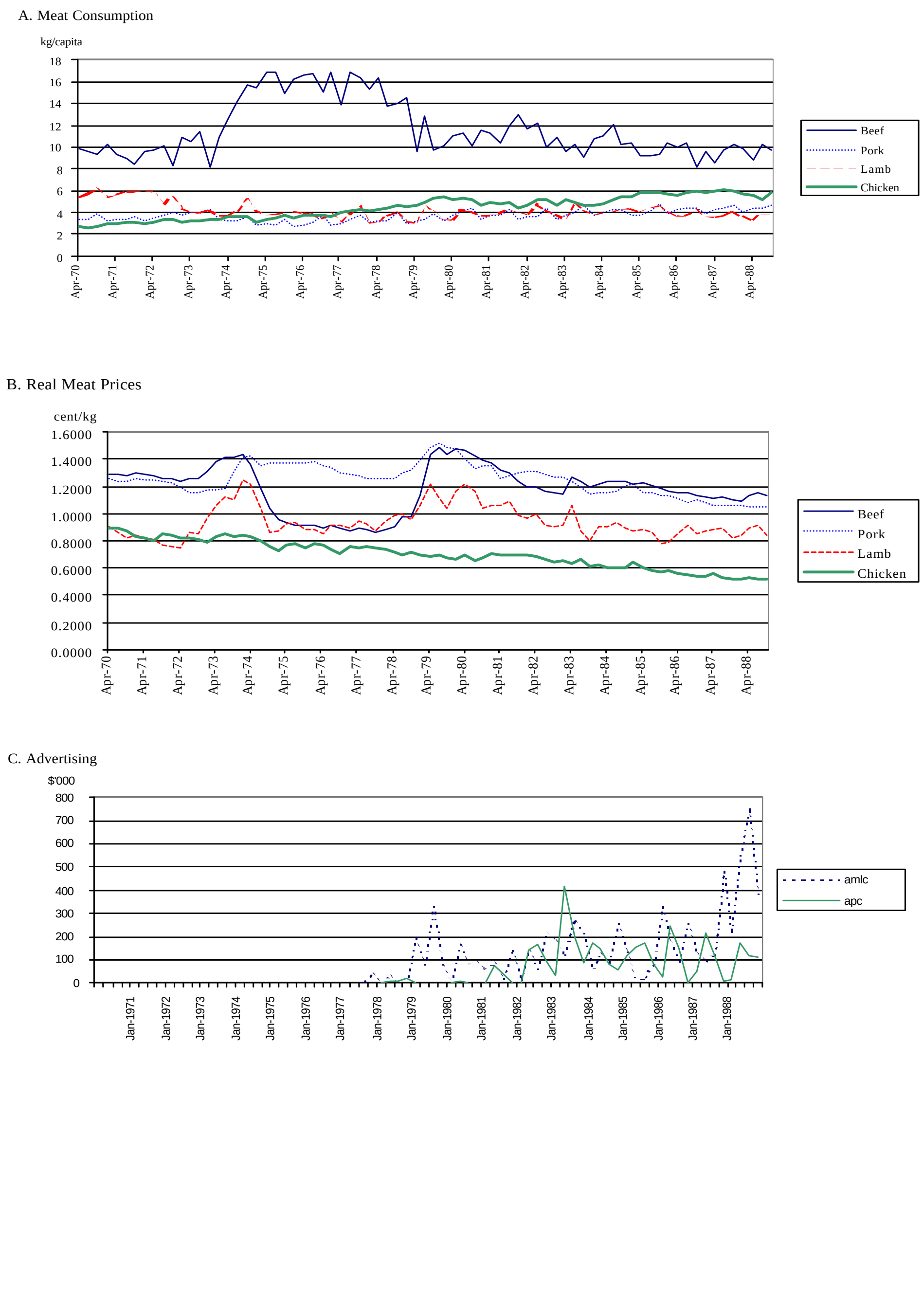

Figure 2: Estimated Taste Changes, No Advertising Variables Included

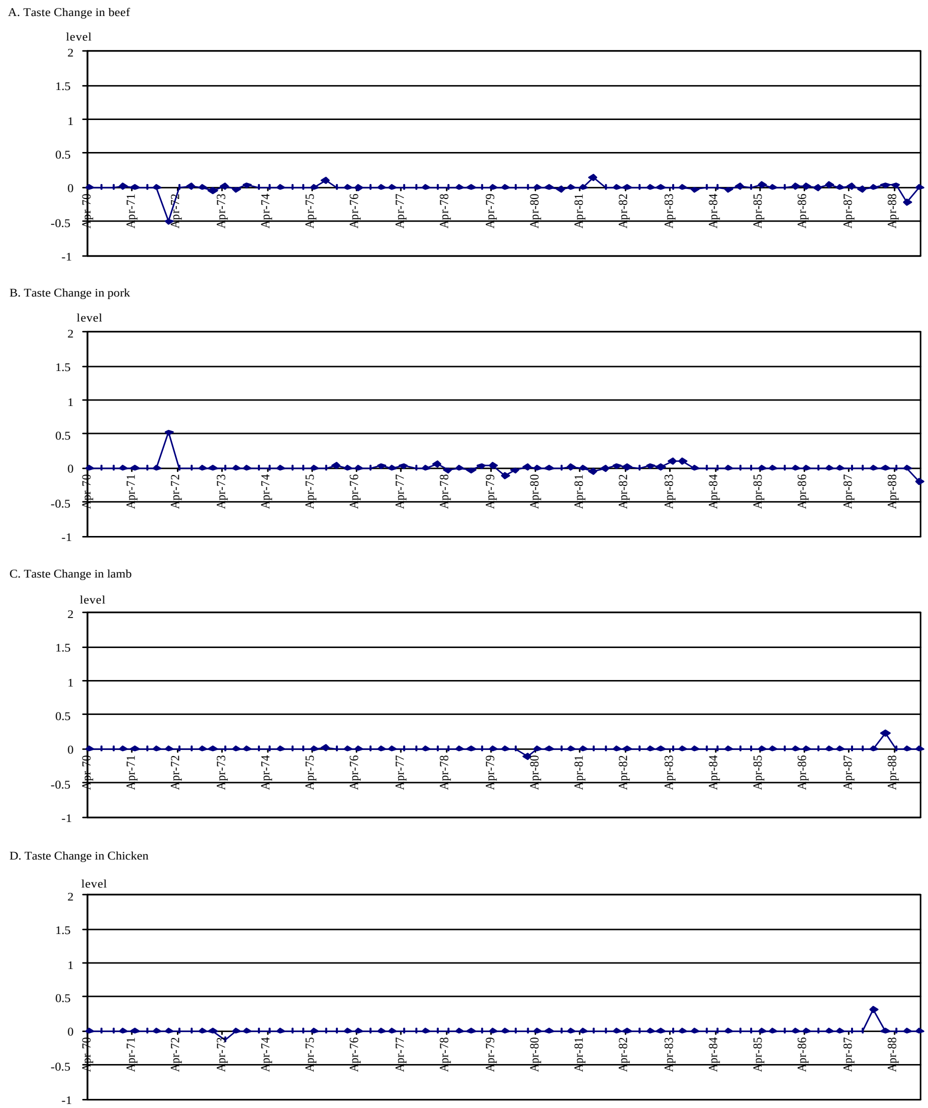

Figure 3: Estimated Taste Changes, No Advertising, Restricted Expenditure Elasticities

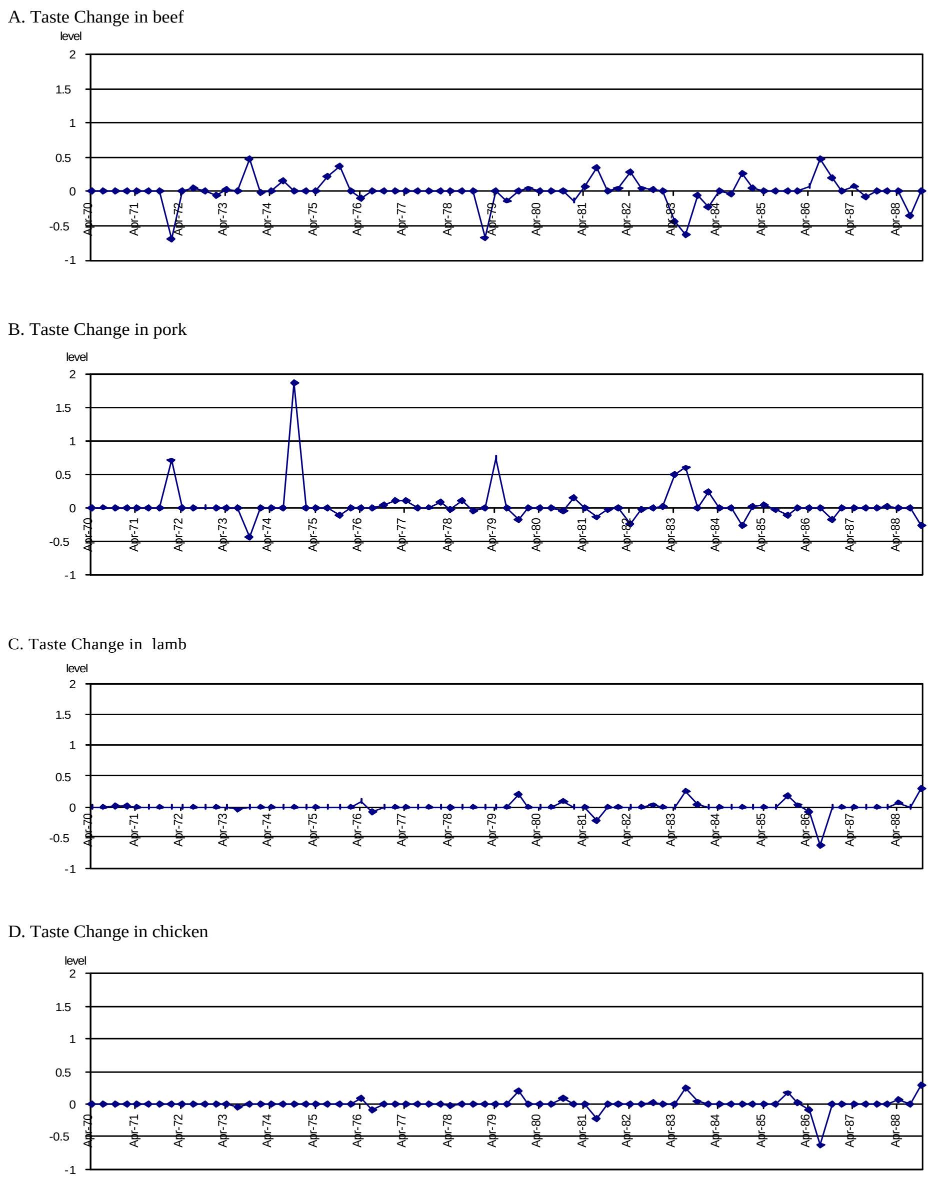

Figure 4: Estimated Taste Changes with Unrestricted Advertising Effects

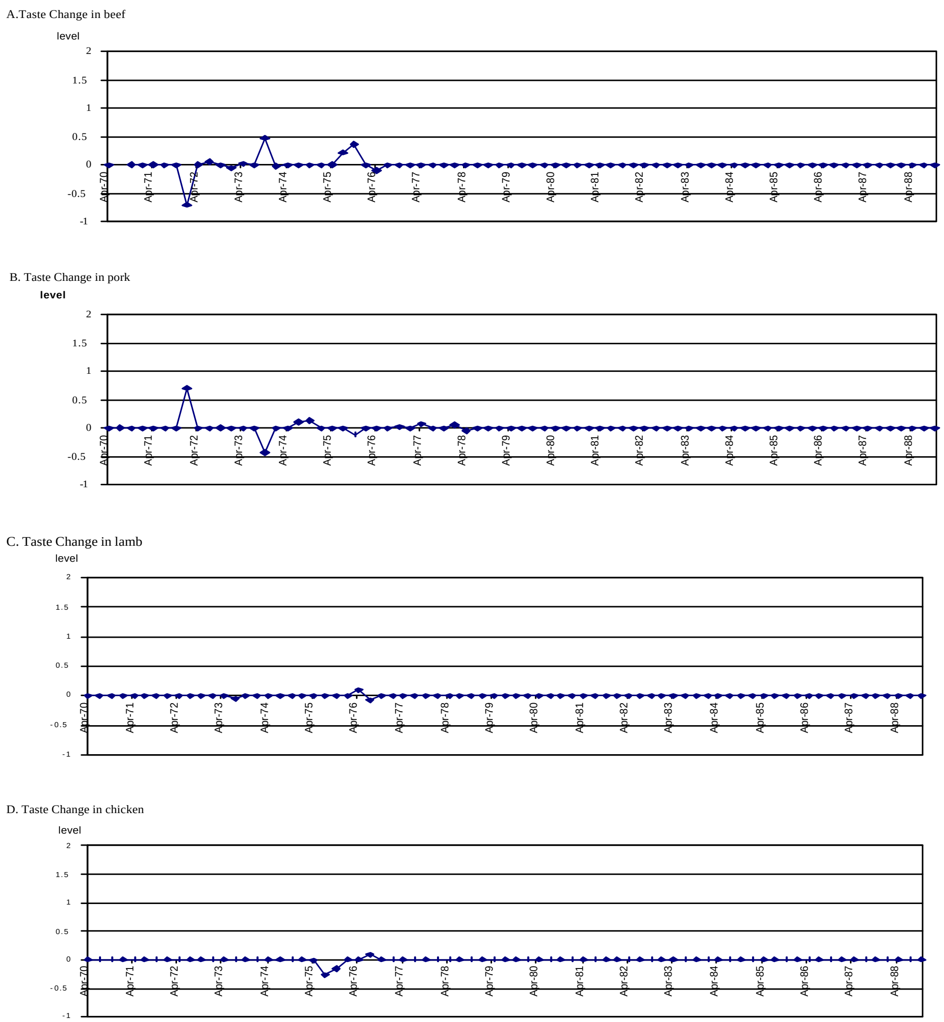

Figure 5: Estimated Taste Changes with Restricted Advertising Effects