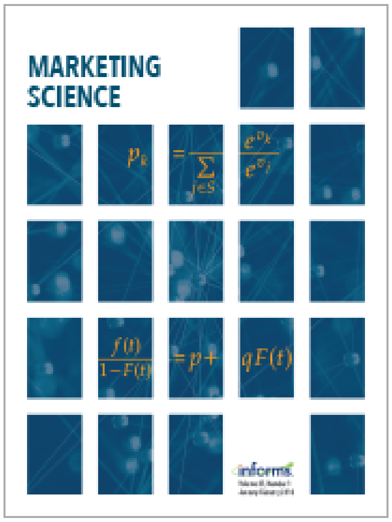

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The Effects of Free Sample Promotions on Incremental Brand Sales

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The authors present a model of free sample effects and evidence from two field experiments on free samples. The model incorporates three potential effects of free samples on sales: (1) an acceleration effect, whereby consumers begin repeat purchasing of the sampled brand earlier than they otherwise would; (2) a cannibalization effect, which reduces the number of paid trial purchases of the brand; and (3) an expansion effect, which induces purchasing by consumers who would not consider buying the brand without a free sample. The empirical findings suggest that, unlike other consumer promotions such as coupons, free samples can produce measurable long-term effects on sales that can be observed as much as 12 months after the promotion. The data also show that the effectiveness of free sample promotions can vary widely, even between brands in the same product category.

Application of the model to the data from the two experiments reveals that the magnitude of acceleration, cannibalization, and expansion effects varies substantially across the two free sample promotions. These and other findings suggest that the model can be a useful tool for obtaining insights into the nature of free sample promotions.

Key words: free samples; samples; promotions; field experiments; incremental volume; coupons; incremental sales; sampling programs; consumer products; panel data; repeat purchasing; long-term effects
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The distribution of free samples is a common and important promotional tool for many products (Schultz et al. 1998). For example, a 1994 survey of packaged goods manufacturers (Donnelley 1994) indicates that 78% of firms surveyed distributed free samples in that year. A 1997 poll in the United Kingdom (*Marketing Week* 1997) indicates that 84% of adults had experienced some form of free sampling in the prior 6 months. Marketing scholars, too, have noted (e.g., Villas-Boas 2004, Seetharaman 2004) that free samples can play an important role in creating brand loyalty and inertia.

There appear to be two lacunae in the literature on free samples. First, although free samples are widely used, empirical evidence to demonstrate their effects on sales over time is extremely limited. In particular, it appears that no controlled field experiments have been reported that measure the incremental effects of free sample promotions. Such evidence as exists does not provide a clear basis for understanding or predicting the full effects of free sample promotions on brand sales.

Second, relatively few models have been developed for the analysis of free sample promotions. Existing models that incorporate free sample effects include those by Jain et al. (1995), Heiman et al. (2001), Urban and Hauser (1980), and Gedenk and Neslin (1999). While each of these models provides useful insights, we see a need for a comprehensive model that more directly focuses on the incremental sales effects of sampling and its impact on different consumer segments.

The specific objectives of this study are:

(a) To develop a model showing the expected dynamic effects of a free sample on the purchase behavior of consumers in different segments;

(b) To analyze data from two controlled field experiments to determine the extent of incremental volume and the dynamic responses of consumers to free sample promotions;

(c) To determine whether free samples produce a long-term change in purchasing (i.e., conversion) of a brand, or whether they produce only a short-term increase in sales, as has been consistently observed for coupons (e.g., Klein 1981, Irons et al. 1983); and

(d) To illustrate how one can estimate the parameters for the model and then use them to predict the effects of various changes in the marketing program or product.

Our base model posits that there are three potential effects of free samples. The first is an acceleration effect, which can occur when new customers begin purchasing the brand sooner than they would have had they not received a free sample. The second is a cannibalization effect, whereby usage of the free sample reduces the number of paid trial purchases of the brand among those who otherwise would have purchased the brand to try it. The third is an expansion effect, which increases the number of buyers among those who would not have tried without a free sample promotion.

The acceleration-cannibalization-expansion (ACE) model suggests that the net impact of a free sample promotion on sales may be positive or negative depending on the relative magnitudes of these three effects over time. The model also provides several insights into the dynamic effects of free samples.

The ACE model differs from logit-type models commonly used to analyze promotion effects (e.g., Gedenk and Neslin 1999) in a number of ways. The ACE model assumes that there are three segments of consumers: those who have already tried the subject brand, those who would make a trial purchase of the brand without a free sample, and those who would not purchase the brand unless they could try a free sample. The objective of the model is to gain a better understanding of the incremental sales effects of the promotion. The model's parameters are estimated using purchase data from both a test and a control group. In contrast, the logit model is used to estimate the effects of past promotional purchases on choice probabilities. Gedenk and Neslin's data cover a period when a free sample was delivered, but a control group is not used to estimate the effects of the promotion.

The empirical findings in this paper are based on analyses of scanner panel data from two separate field experiments involving free samples accompanied by a coupon.[1] We find that unlike most consumer promotions, free sample with coupon promotions can have measurable long-term conversion effects that can be observed for as long as 12 months after the promotion and the effects of a free sample promotion can vary widely, even between two different brands in the same product class.

[1] While free samples can be distributed with or without a coupon, our experience is that free sample promotions for consumer packaged goods almost always include a coupon with the sample. Thus the promotion we are studying is the distribution of free samples with a coupon. This focus appears to be managerially more useful than examining the effects of a free sample promotion alone.

Data from the two experiments are used to estimate the parameters in the model. This allows us to decompose the incremental sales effect in each experiment into its components and to gain additional insights into the differences between the two free sample promotions.

The remainder of the paper is organized as follows. We first discuss prior research, existing models, and evidence on free sample effects. Next, the ACE model is presented and its implications are discussed. A simulation model is also developed to examine the sensitivity of model results to some of its assumptions. We then present the findings from two field experiments involving free sample and coupon promotions. Finally, we estimate the model using these experimental data to gain insight into the promotions' effects and to answer various "what if" questions.

Prior Research

Two streams of prior research on free samples are considered. We first review models that incorporate the effects of sampling on sales or market share. We then review empirical results on the effectiveness of free samples.

Prior Models of Free Sample Effects

Two closely related models incorporating free sample effects were developed by Silk and Urban (1978) and by Urban and Hauser (1980, pp. 341–342). The models were developed to predict steady-state market share for new products. No empirical results were presented to show the incremental effect of a free sample promotion on sales.

Jain et al. (1995) develop an interesting simulation approach to determine the optimal level of product sampling for a new product. Their modification of the Bass model assumes that the coefficient of innovation is a function of the sampling level (Jain et al. 1995, Equation 6). While this approach is most promising, it appears that further empirical work is required in order to determine how the coefficient of innovation is related to the level of sampling.

More recently, Heiman et al. (2001) develop a model that decomposes the sampling effort into the immediate sales and longer-run (goodwill-building) effects. Through use of their model, they determine the optimal sampling effort of a firm over time. Their model is designed primarily for the case where products are taste tested at retail outlets. Although they did not conduct any empirical tests of the model, they note that the conceptual model they developed could provide the basis for an empirical investigation and that one would have to develop "practical measures of goodwill" (p. 544).

Empirical Evidence on Free Sample Effects

The belief that free samples can be effective in increasing a brand's franchise appears to be well-accepted among marketers. Many examples of the use of free samples have been reported in the media, although few data on their effectiveness are provided. For example, Lever Brothers distributed free samples of its new Surf detergent to four out of five households in the United States (Kotler 1990, Chapter 23). Frito-Lay distributed more than 6 million free samples of Nacho Cheese Flavored Doritos to introduce this new snack (*Brandweek* 1995). The distribution of free samples to physicians (i.e., detailing) by pharmaceutical firms has long been a popular form of promotion (Wosinska 2001).

Relatively few studies, however, have been published to show the effectiveness of free samples. A study by Scott (1976) predicts the impact of various promotions on demand for newspaper subscriptions. Among subjects given a free 2-week trial subscription, only 4% were willing later to subscribe for a 6-month period, compared with a 9% subscription rate in the control group. This demonstrates that the achievement of trial via a free sample does not necessarily lead to increased sales or to conversion. Subscriber behavior after the initial trials was not reported.

In a field experiment, Lammers (1991) offered a free sample of chocolate to customers who entered a retail chocolate store. In the very short term (within minutes of sampling), providing a free sample had a positive impact on sales of other chocolate varieties, though not of the sampled variety. As a result, his findings would be most relevant to retailers wanting to examine the short-term effects of a free sample on category purchases, rather than purchases of the sampled brand.

Prior research has also demonstrated the positive effects of free samples on measures such as belief strength and attitude (Marks and Kamins 1988), perceptions of the brand (Bettinger et al. 1979, Hamm et al. 1969), and the initiation of interpersonal communication about the brand (Holmes and Lett 1977). While these studies did not examine the effects on sales nor measure any long-term effects, they suggest that free samples could cause some households to make a trial purchase that would not have been made without a free sample promotion.

Surveys conducted by the Sunflower Group (1997) suggest that the incidence of consumers using the product (via usage of the free sample) is several times that which is commonly achieved with other promotions, such as coupons. For example, in one survey 32% of respondents report that they had used the free sample within one day of receiving it. This is much higher than the typical redemption rate for a coupon (Blattberg and Neslin 1990).

Gedenk and Neslin (1999) develop a new logit model and estimate the effect of in-store promotions on purchase event feedback, i.e., brand loyalty (BLOY). They find that the estimated coefficients were positive for in-store samples of mineral water and negative for price cuts. Thus, the distribution of these free samples is associated with a higher probability that the households would choose this brand in the future, whereas a price cut has the opposite effect. It should be noted that with in-store samples buyers are able to purchase the subject brand immediately after using the sample, while with home-delivered samples, there would generally be a longer interval until the first purchase opportunity. In addition, there could be a reciprocity effect, whereby the consumer feels obliged to make a purchase because of the personal nature of the free sample delivery. Thus the results for home delivery and in-store delivery of free samples could differ.

In summary, given that free samples have been used for a long time and that considerable money is spent on free samples, it is surprising that more research on free samples has not been reported. Second, there do not appear to be any controlled field experiments other than the study by Scott (1976) on newspaper subscriptions. Third, with the exception of the Gedenk and Neslin (1999) study on in-store sampling, there do not appear to be any empirical studies that have examined the effects of free samples beyond the first 2 weeks after their delivery.

Modeling the Effects of a Free Sample Promotion

The increase in manufacturer profits due to a promotion is given by the number of incremental purchases times the margin per unit, less the extra costs incurred as a result of the promotion (Irons et al. 1983). As a result, both the modeling effort and our empirical analyses will focus on total sales with the promotion minus total sales without the promotion, accumulated over time.

We posit that there are three potential effects of free samples on incremental consumer purchasing. These are referred to as the acceleration, cannibalization, and expansion effects. One objective in developing a model is to decompose the aggregate effect of the free sample into the acceleration, cannibalization, and expansion effects for a better understanding of free samples.

To keep the model as general as possible, we initially assume that the brand for which a free sample is being provided has been available in the market for some time. As will be seen, the introduction of a new brand can be treated as a special case of the general model where the initial level of market penetration is zero.

To begin, we divide consumers in the brand's target market into three segments. Segment 1 consists of *prior triers*, i.e., all households that have purchased the subject brand prior to the free sample promotion. Segment 2 consists of *likely triers*, i.e., households that have never purchased the brand but have a positive probability of making a trial purchase of the brand even if no free sample is delivered. Their willingness to try the brand could come about as a result of many factors, such as exposure to advertising, word of mouth, in-store displays, or innate curiosity. However, depending on their probability of trial, they may not make a trial purchase until several purchase occasions have elapsed.

Segment 3 consists of *nontriers*, i.e., households who would never make a first purchase of the brand if they could not try the brand first via a free sample. This behavior might occur because they are unaware of the brand, are not interested in using it, or are not willing to take the risk of purchasing the brand. In the case of brands with small market shares, the size of this nontrier segment could be quite large (Parfitt and Collins 1968).[2]

How will delivery of a free sample affect these three segments? Households in Segment 1 (prior triers) are unlikely to be affected by the free sample, because these households have already experienced the brand.[3] As will be shown later, this assumption is consistent with our data.

If a free sample is delivered to Segment 2 households, it is assumed that some of them will like the brand and, as a result, they will start purchasing the brand sooner than they would have if no free sample were delivered. This positive effect of the free sample on Segment 2 is termed the acceleration effect.

At the same time, it is assumed that some other members of Segment 2 will not like the new brand after trying the free sample and decide not to make any purchases of the brand (Allioni-Charas 1994). As a result, the paid trial purchases that these households in Segment 2 would have made are eliminated, and the total number of paid trial purchases is reduced. We will refer to this permanent loss of trial purchases as the cannibalization effect. In the limit, if almost all users of the free sample dislike the brand, there would be no reason for these households to pay for a trial purchase and the free sample promotion would produce a severe negative impact on sales of the brand. In summary, the acceleration effect is positive and the cannibalization effect is negative. Both effects are relevant for Segment 2 buyers.

If a free sample is delivered to Segment 3 (nontriers), we assume that some fraction of them will like the product and start purchasing the brand. These are sales that would not be realized if the free sample were not delivered. We will refer to this as the expansion effect. The expansion effect could be zero if none of these consumers reacts positively to the free sample.

The total impact of the free sample on brand purchasing is the sum of the acceleration and cannibalization effects on Segment 2 and the expansion effect on Segment 3. Depending on the magnitudes of these effects and the number of periods considered, the net impact of the free sample promotion on unit and dollar sales could be positive or negative.

When presenting the model in the following section we assume that consumers within each segment are heterogeneous in terms of trial purchase probability and in terms of the brand purchase probability subsequent to the trial usage or trial purchase. In particular, we assume that these probabilities have beta distributions across all households within each market segment. We initially assume that the trial and brand purchase probabilities are distributed independently and that each household makes one purchase of the product class in each period. In the simulation model presented subsequently we allow different households to have different probabilities of buying the product class (see Appendix B). We also test to determine how the results would be affected if the trial and brand choice probabilities were positively correlated.

Base Model

Let

t_{ij} = probability that household j in Segment i ($i = 2, 3$) makes a trial purchase of the brand on a given purchase occasion in the absence of a free sample, with $t_{2j} \sim \text{Beta}(\alpha_0, \beta_0)$, with mean t_2, and $t_{3j} = 0$

n_i = segment size, i.e., number of consumers in Segment i ($i = 1, \ldots, 3$)

r_{ij} = probability that household j in Segment i ($i = 1, \ldots, 3$) buys the brand on any purchase occasion after trial usage of the brand (via the free sample or a trial purchase), with $r_{ij} \sim \text{Beta}(\alpha_i, \beta_i)$ with mean r_i

K = number of periods or purchase occasions observed.

In the case where a free sample is delivered, K denotes the number of periods from the time of delivery. We refer to this period as the observation period. Because each household is assumed to make one purchase per period, the number of purchase occasions observed is also given by K.

[2] It is assumed here that the size of the free sample is a trial size. Appendix A considers the case of a free sample that is a full-size package.

[3] There could be a reminder effect of the free sample on these prior triers. However, in the aggregate this effect is likely to be quite small relative to the other effects of the promotion. We assume for simplicity that the reminder effect is negligible. This assumption appears to be appropriate for our data, but may not necessarily hold for other brands or free sample promotions.

By definition, Segment 3 has zero trial of the brand before receiving the free sample. That is, $t_{3j} = 0$. We first consider the case where there is no sampling, and then the case where a free sample is delivered to all segments. In the final step, we examine the difference between the sampling and no sampling cases to determine the incremental impact of the free sample. We also show how the incremental impact can be decomposed into the acceleration, cannibalization, and expansion effects.

Brand Purchasing in the Absence of a Free Sample. First, consider purchases made by the n_1 consumers in Segment 1, that is, the consumers who tried the brand prior to the observation period. Because they have an average probability r_1 of purchasing the brand on each of K occasions, they are expected to make a total of $R_1 = n_1 K r_1$ purchases.

Next, consider the n_2 households in Segment 2. In the absence of a free sample, the probability that each of the n_2 likely triers will make a trial purchase of the brand over K purchase occasions, given a trial probability t_{2j} on any occasion, is 1 minus the probability of not making any trial purchases over K purchase occasions, or $[1-(1-t_{2j})^K]$. Thus the expected number of new trial purchases by Segment 2 in the absence of a free sample, T_2, is given by

$$T_2 = n_2 \int \{1-(1-t_{2j})^K\} f(t_{2j} \mid \alpha_0, \beta_0)\, dt_{2j}.$$

This integrates to

$$T_2 = n_2 \left[1 - \frac{\Gamma(\alpha_0+\beta_0)\Gamma(\beta_0+K)}{\Gamma(\beta_0)\Gamma(\alpha_0+\beta_0+K)}\right]. \tag{1}$$

However, if a free sample is delivered to these n_2 likely triers, we assume it would eliminate their need to make paid trial purchases. Because T_2 represents the expected number of trial purchases lost due to the free sample, T_2 also equals the cannibalization effect of the free sample.

Now consider repeat purchasing in Segment 2 by those who try the brand after the beginning of the analysis period and decide to make a repeat purchase of the brand. Because we are considering a fixed number of purchase occasions in the market (K occasions, including the first purchase), and because a consumer might make a trial purchase on any one of the K occasions, the number of opportunities for a consumer to repurchase the brand will depend on when the trial purchase takes place.

The first opportunity to make a repeat purchase is on occasion 2 among the consumers who tried the product on occasion 1. The expected number in Segment 2 who will make a trial purchase in period 1 is $n_2 t_2$. These consumers have a probability r_{2j} of repurchasing it on each subsequent occasion. Because they have $K-1$ occasions to make repeat purchases, the expected number of repeats for those who are able to make a repeat purchase starting with occasion 2, $E(V_2)$, is given by

$$E(V_2) = n_2(K-1) \int t_{2j} f(t_{2j} \mid \alpha_0, \beta_0)\, dt_{2j} \cdot \int r_{2j} f(r_{2j} \mid \alpha_2, \beta_2)\, dr_{2j}. \tag{2}$$

More generally, consumers who make a trial purchase of the brand on occasion k ($k = 1, \ldots, K$) have $(K-k)$ opportunities to repurchase it, and some fraction r_2 are expected to do so on each of those occasions. The expected total number of repeat purchases R_2 made by all triers over the K occasions is given by

$$R_2 = \sum_{k=2}^{K} E(V_k) = n_2 \sum_{k=0}^{K-2} (K-k-1) \int r_{2j} f(r_{2j} \mid \alpha_2, \beta_2)\, dr_{2j} \cdot \int t_{2j}(1-t_{2j})^k f(t_{2j} \mid \alpha_0, \beta_0)\, dt_{2j}, \tag{3}$$

which integrates to

$$R_2 = \sum_{k=0}^{K-2} (K-k-1) n_2 r_2 \alpha_0 \frac{\Gamma(\alpha_0+\beta_0)\Gamma(\beta_0+k)}{\Gamma(\beta_0)\Gamma(\alpha_0+\beta_0+k+1)}. \tag{4}$$

R_2 represents the total number of repeat purchases in Segment 2 among those who first tried the brand during the observation period.

Next, consider Segment 3. By assumption, there will be no trial or repeat purchases in Segment 3 in the absence of a free sample. Therefore the total number of purchases P for the brand in the absence of a free sample is the sum of the trial and repeat purchases made by Segment 1 and 2 consumers:

$$P = R_1 + T_2 + R_2. \tag{5}$$

Brand Purchasing After a Free Sample Promotion. We assume to start with that the free sample is delivered to all consumers in all segments (i.e., a 100% sampling rate). Alternative assumptions about the sampling rate can be accommodated, and will be discussed later. We assume that the free sample will have no effect on the households in Segment 1 because they already have had an experience with the brand. They are expected to make $R_1 = n_1 K r_1$ purchases, as in the case where no free sample is offered.

For those in Segment 2, we assume that the free sample will eliminate the need for a trial purchase. Because there are n_2 consumers who have not yet tried the brand, the expected number of subsequent purchases they make, S_2, will depend on the probability r_{2j} of their purchasing it on each of the K purchase occasions:

$$S_2 = n_2 K r_2. \tag{6}$$

We note that Equation (6) shows the total number of repeat purchases over K occasions after delivery of a free sample. In contrast, Equation (4) shows the number of repeat purchases over K occasions in the absence of a free sample promotion. We will call the difference between Equations (6) and (4) the acceleration effect. This acceleration term is greater for higher values of n_2 and r_2, and is smaller for a higher value of t_2. That is, if the trial rate is high even without a free sample, or if the purchase probability after trial is low, this acceleration effect will be small.

In Segment 3, the expansion effect of the free sample will pull in new buyers who might also purchase the brand subsequently if they have a positive experience with the free sample. This yields new sales S_3:

$$S_3 = n_3 K r_3. \tag{7}$$

We shall refer to S_3 as the expansion effect. The expected number of total purchases Q of the brand in the sampling case therefore is

$$Q = R_1 + S_2 + S_3. \tag{8}$$

Incremental Sales Effect of the Free Sample Promotion. The expected difference D between the sampling and nonsampling cases is given by

$$D = Q - P = R_1 + S_2 + S_3 - R_1 - T_2 - R_2. \tag{9}$$

Substituting (1), (4), (6), and (7) and rearranging the terms, we get

$$\begin{aligned} D = {} & n_2 r_2 \left\{ K - \alpha_0 \frac{\Gamma(\alpha_0+\beta_0)}{\Gamma(\beta_0)} Z \right\} + \{n_3 K r_3\} \\ & - n_2 \left\{ 1 - \frac{\Gamma(\alpha_0+\beta_0)\Gamma(\beta_0+K)}{\Gamma(\beta_0)\Gamma(\alpha_0+\beta_0+K)} \right\}, \end{aligned} \tag{10}$$

where

$$Z = \sum_{k=0}^{K-2} (K-k-1) \left[\frac{\Gamma(\beta_0+k)}{\Gamma(\alpha_0+\beta_0+k+1)} \right].$$

The first term in (10) represents the acceleration effect for Segment 2, the second term the expansion effect due to Segment 3, and the last term the cannibalization effect on Segment 2. The acceleration and cannibalization effects approach asymptotic values as K increases, while the expansion effect grows linearly with K. Consequently, although the net effect on sales might be negative initially, as long as r_3 and n_3 are positive the net effect will eventually become positive as K increases. However, if r_3 is small it might take a long time (i.e., many purchase occasions) for the net effect to become positive. In addition, if one discounts the dollar value of future sales, the present value of future profits due to the free sample might always remain negative, even if the cumulative net effect eventually becomes positive.

If one makes the simplifying assumption of within-segment homogeneity in trial probabilities (t_{ij}) and posttrial purchase probabilities (r_{ij}), Equation (10) takes the following form:

$$D = \left\{ n_2 r_2 \left[\frac{1-(1-t_2)^K}{t_2} \right] \right\} + \{n_3 r_3 K\} - \{n_2[1-(1-t_2)^K]\} \tag{11}$$

The derivation of (11) is available from the authors.

Modifying the Model to Include Coupon Effects

As noted earlier, many free sample promotions also include a coupon with some price savings for a future purchase of the brand. Let δ_1, δ_2, and δ_3 represent the proportion of consumers in Segments 1, 2, and 3, respectively, that redeem the coupon accompanying the free sample. Let P_{ri} be the proportion of redemption purchases in Segment i ($i = 1, \ldots, 3$) that are incremental purchases of the promoted brand, with $0 \leq P_{ri} \leq 1$. We assume that these buyers who do make an incremental purchase will revert to their normal (i.e., precoupon) behavior after using the coupon. That is, consumers in Segments 1, 2, and 3 who make an incremental purchase with a coupon will subsequently buy the brand with probabilities r_{1j}, r_{2j}, and r_{3j} respectively. The assumption that consumers revert to their precoupon behavior following the coupon redemption is consistent with the findings of Irons et al. (1983) and Bawa and Shoemaker (1987) that coupons typically cause a temporary brand switch but do not lead to long-term changes in purchase probability.[4] This assumption is also consistent with our data (see Footnote 11).

The remaining proportion $1 - P_{ri}$ of redeemers and those consumers who do not redeem the coupon in segment i ($i = 1, \ldots, 3$) are expected to purchase the brand with probabilities r_{ij}. We also assume that a household's probability of redeeming a coupon is independent of the household's noncoupon probability r_{ij} of purchasing the brand subsequent to trial. Given these assumptions, one can show that the cumulative difference in sales (test minus control)

[4] Studies on coupons have mainly been based on coupons for established brands. The buyer behavior for a new brand could differ, with the coupon leading to an increase in the purchase probability for the brand.

with a free sample and a coupon is given by

$$D_C = D + n_1\delta_1 P_{r1}(1-r_1) + n_2\delta_2 P_{r2}(1-r_2) + n_3\delta_3 P_{r3}(1-r_3). \quad (12)$$

Because the last three terms on the right-hand side of (12) are nonnegative, the implication is that the volume of incremental sales generated by a free sample and coupon promotion is greater than in the case of a free sample without a coupon, as long as P_{ri} and some of the δ_1, δ_2, and δ_3 are positive. As will be shown in the empirical analyses, the level of incremental coupon redemptions was quite low when the coupon was delivered with a free sample in our field experiments. As a result, we use the base model (Equation (10)) in this study rather than (12).

Model Implications

An examination of Equations (10) and (11) shows several interesting implications of the model. First, if the mean repeat purchase probabilities r_2 and r_3 (i.e., the ratios $\alpha_2/(\alpha_2+\beta_2)$ and $\alpha_3/(\alpha_3+\beta_3)$) are small, the net impact of the free sample could be negative for an extended period of time. That is, if repeat purchasing following brand trial is low or nonexistent (due, for example, to consumer dissatisfaction with the product), the free sample is likely to cannibalize trial purchases that might otherwise have occurred. This phenomenon is consistent with the observation of Allioni-Charas (1994), where he indicates that "... the quicker consumers know that a new product will not meet their expectations of satisfaction, the quicker its demise."

A second implication is that the free sample promotion might have a persistent or long-term impact on brand sales. This can occur in several ways. First, the acceleration effect and the cannibalization effect (the first and last terms in (10) and (11)) might not converge to asymptotic levels until K, the number of time periods observed, is quite large. Second, the expansion effect might continue to generate incremental sales for an extended period of time. Any of these effects, alone or in combination with the others, can lead to a potential long-term impact of the free sample.

Third, the cumulative effect of the free sample on sales depends upon K. When K is small the cumulative effect could be negative, but as K increases it is more likely that the cumulative effect on sales will be positive. Because we are initially assuming one purchase of the product class per period, this suggests that a free sample for a frequently purchased product is more likely to produce positive effects within a given time interval than for an infrequently purchased product, other things being equal.

Fourth, the three effects depend directly upon the relative sizes of Segments 2 and 3 (likely triers and nontriers). For a new product introduction, where Segment 3 is large relative to Segment 2, a free sample is likely to be more helpful than in the case of an established product, because the expansion effect on Segment 3 is positive and increasing over time. Similarly, brands with lower market penetration (i.e., a smaller proportion of consumers in Segment 1) are more likely to generate incremental purchasing relative to brands with higher penetration, which have fewer nontriers left to convert to brand users.

Finally, the extended model in Equation (12) suggests that the inclusion of an effective coupon with the free sample could produce incremental sales beyond the free sample alone. The profitability of including a coupon would depend on what percent of the redemptions were incremental and how large a face value was required to produce a significant number of redemptions.

To summarize, the model predicts that the effectiveness of sampling is greatest for brands that have low penetration (low n_1), a low average trial rate (t_2), a large number of Segment 3 consumers (n_3), a high average purchase probability following trial of the brand (high r_2 and r_3), and a high frequency of purchase (large K) for the product category. In addition, the impact on incremental volume might be enhanced if a coupon is delivered with the free sample.

A major advantage in having a model, as in Equation (10), is that it can be used, once its parameters are estimated, to answer a number of "what if" questions for a specific brand. For example, what would be the relative impact of increasing the trial rate by 10% versus modifying the product to cause a 10% increase in the average brand purchase probability? In a later section of the paper we use the model to address these and related questions for the data in our study.

Model Extensions

The basic model described above can be modified in several ways to predict the effects of alternative marketing actions or scenarios. We initially assumed a 100% sampling rate and a 100% usage of the free sample. However, alternative sampling or usage rate scenarios can easily be accommodated via additional parameters. For example, suppose the usage rate of the free sample differs for Segments 2 and 3 (we ignore Segment 1 in this analysis because we assume those consumers' purchase behaviors to be unaffected by the free sample). Let Φ_2 and Φ_3 be the usage rates in Segments 2 and 3 respectively. It can be shown that the total incremental sales D_Φ after K occasions is given by

$$D_\Phi = \Phi_2[S_2 - T_2 - R_2] + \Phi_3[S_3], \quad (13)$$

where T_2, R_2, S_2, and S_3 are as defined in Equations (1), (4), (6), and (7). If the usage or sampling rate is the same in both segments (i.e., $\Phi_2 = \Phi_3 = \Phi$), it can be seen that the usage rate merely scales the total number of incremental purchases (i.e., $D_\Phi = \Phi D$). A 10% sampling rate, for example, would result in 10% of the number of incremental purchases.

Second, we have assumed that the product being sampled is an existing product that has already been tried by some consumers (designated as Segment 1). However, the model could readily be applied to a new product by setting n_1, the size of Segment 1, to zero.

Third, we have assumed that the free sample consists of a trial-size package, and therefore usage of the free sample by a household does not reduce the amount purchased by that household on a future occasion. While this is generally true of most free sample promotions in our experience, the model can also be extended to promotions where the free sample consists of a full-size package that potentially reduces the amount purchased in future by the household. In this case the expression for incremental volume needs to be adjusted downward. Details are shown in Appendix A.

Incorporating Heterogeneity in the Product Class Purchase Rates

In developing the expression for the cumulative level of incremental sales (D in Equation (10)), we allowed for heterogeneity in the trial probabilities t_{ij} and the brand choice probabilities r_{ij} but assumed that each household had the same probability of purchasing the product class. We now relax the latter assumption and permit households to have different product class purchase probabilities (PCPP). Monte Carlo simulation is conducted to determine whether the predictions from the model are affected if we assume heterogeneity in PCPP.

The simulation model is described in Appendix B. In the first series of simulations, we assumed that the household's PCPP was distributed independently of its brand choice probability r_{ij}. These tests showed that the cumulative difference in sales derived from the simulated data (free sample group sales minus control group sales) was quite similar—within 1%—whether we assumed homogeneity or heterogeneity in PCPP.

A second series of simulations was conducted to simulate conditions where brand choice probabilities were correlated with PCPP (see Appendix B for details). When the correlations were negative (−0.36, −0.36, and −0.42 for Segments 1, 2, and 3, respectively) the simulated cumulative difference in sales was 20.8% less than the base case, where there was almost no correlation (−0.05, −0.05, and −0.01). When the correlations were positive (0.37, 0.37, and 0.38), the simulated difference in sales between the test and control groups was 25.5% higher than in the base case of no correlation. This occurred because the heavy buyers in the simulation tended to have higher brand choice probabilities. It should be noted, however, that the correlation between brand choice probabilities and product class purchase frequencies is unlikely to be high in practice (Shoemaker et al. 1977).

A final simulation analysis was conducted to determine the impact of a positive correlation between the trial purchase probabilities t_{2j} and the brand choice probabilities following trial (r_{ij}). Using the method described in Appendix B, we induced a correlation of 0.3 between these variables. This has the effect of producing more sales among those who do not get the free sample. The result was a reduction of 10.7% in the overall effect of the free sample. Thus if this type of correlation was found to exist, our prediction is that the free sample would be somewhat less effective.

Data

Two experiments are studied. They involve free sample promotions for different brands within the same product category. In Experiment 1 the sampled brand enjoys a relatively high market share, while in Experiment 2 the sampled brand has a lower share. This variation in shares allows us to examine the effects of the free sample under different market conditions. In both experiments we find that the free sample and coupon promotion generates incremental sales relative to the control group. We first describe the common aspects of the two experiments and then discuss each experiment separately.

Common Aspects of the Two Experiments

Both experiments are controlled experiments and were conducted by Information Resources Inc. (IRI) using scanner panels. The experiments were designed and executed prior to our request for the data. Their design is particularly appropriate for analyzing free sample effects in that each study had a control group that did not receive the promotion. Not only does this provide a benchmark for assessing changes in purchase behavior following the promotion, but also it controls for external effects such as competitive activities, holidays, changes in retail distribution, other promotions, advertising for the subject brand, and many other factors that could affect the sales of the subject brand over time. Furthermore, in each experiment the data were collected at the level of individual households for 52 weeks before the promotion and 52 weeks after the promotion.

Both experiments were conducted on new brands within the same product category. The two experiments were conducted in different geographic areas and over different time periods. In each case the new brand was a significant modification of an existing brand and was available for at least a year before the promotion.[5] The new brands each had the same umbrella brand name as the original, but had a new brand name, a different shape, and a different package design. This would be analogous to introducing the Diet Coke brand after the introduction of the original Coke brand. As a condition for the use of the data from these two experiments, we are not able to identify the specific brands or the category. However, we can describe the product category as follows: It is a consumer product that is consumed on a regular basis by most households in the United States. Members of a household commonly use different brands in the category. Examples of categories fitting that requirement are soft drinks, snacks, toothpaste, and hand soap. The product is used by a large number of age groups. Households' median purchase frequency is considerably above 10 purchases of the product category per year. Seasonality is not an important factor for this product class.

Each experiment covers a 2-year period (104 weeks) in the mid-1990s. In both experiments, the test stimuli were delivered at the start of the first week in the second year of the data. In both experiments the free sample was delivered with the Sunday newspaper. Thus to test the effects of the free sample promotion, both the test and control scanner panels were formed only with households that received a home-delivered Sunday paper.

To provide the appropriate basis for analysis, we created static panels consisting of households who made at least one purchase of the product class in each of the four 6-month periods covered by the data. This was done for both datasets. The static panels contained at least 83% of the households in the original datasets, and these households accounted for 97% or more of the original purchase records.

Experiment 1

The purpose of Experiment 1 was to compare the effect of a free sample and coupon promotion relative to no promotion. The basic experimental design was "Before-After with Control Group." The panel, consisting of over 4,000 households, was split by IRI into two matched groups, hereafter referred to as the test group ($n = 2,059$ households) and the control group ($n = 1,994$ households). These two groups were matched to be roughly equal (per household) in terms of purchasing the subject brand and the product class during the first year (weeks 1 through 52), or prepromotion period. Starting with the first week of the second year (week 53), a pouch containing a single-serving free sample and a 75-cent coupon for the subject brand was delivered to the test group households in conjunction with delivery of the Sunday newspaper. The free sample contained enough product for one usage occasion by one person. The coupon had an 8-week expiration period. The matched control group did not receive any special promotion for the subject brand at this time.

There are two varieties of the subject brand: the original brand and a relatively new brand that differed from the original in its size, shape, packaging, and brand name. The new brand had been available for at least a year prior to the promotion and had roughly the same sales level as the original. Whereas the free sample consisted only of the new brand, the coupon enclosed with the free sample could be used for either the new or original brand. Because the free sample and coupon could have an effect on sales of both brands, the total impact of the promotion was evaluated by examining total sales for the brands (i.e., for both varieties) rather than just the new brand.

The subject brand is not one of the market share leaders in the category, but is a national brand with a substantial market share that enjoys wide distribution across the United States. In our sample, 28% of households had bought the brand (original or new variety) at least once in the 52-week prepromotion period.

Results

The free sample promotion in Experiment 1 produced a significant increase in sales relative to the control group. The higher sales rate in the free sample group was still evident 52 weeks after the promotion. The duration of this effect is much longer than the effects commonly observed for coupons and temporary price promotions.

Column 2 in Table 1 shows the average change in sales volume (postperiod volume minus preperiod volume) per household that made at least one purchase of the new brand. As can be seen, the total

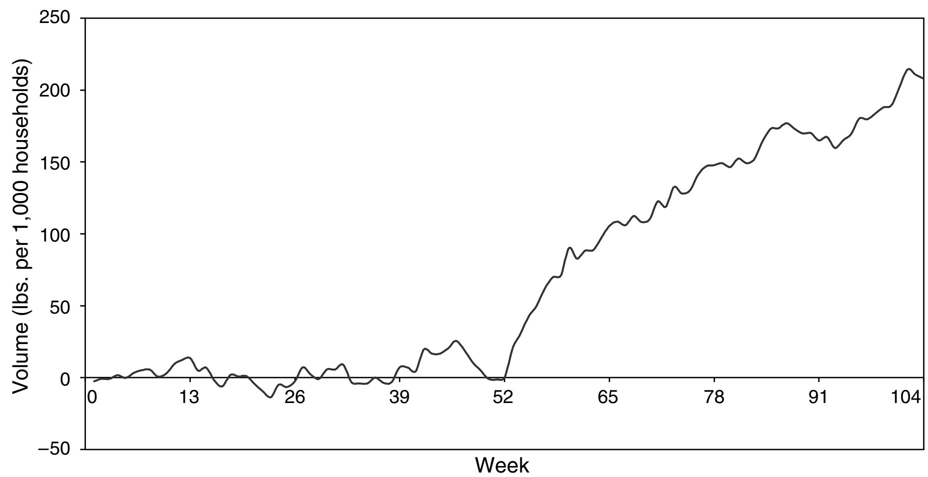
Table 1 Experiment 1: Average Change in Volume per Trier Household

Group	Average change in volume[a]	No. of triers (percent of group)[b]
Control	-0.375[c] (0.143)	743 (37%)
Free sample and coupon	0.176[c] (0.143)	796 (39%)

[a] Standard errors are in parentheses.
[b] Number and percent of households who purchased the brand at least once in the 2-year period.
[c] Change in total volume is significantly different across groups ($p < 0.01$) based on a t-test.

[5] The manufacturers considered the new products to be sufficiently different from existing ones that the use of sampling programs was seen as appropriate. A consumer could like the original but not like the new brand, or the reverse. For this reason, it was believed that free samples might be effective.

Figure 1 Experiment 1: Adjusted Cumulative Difference (Test-Control) in Sales Volume per 1,000 Households



increase in volume per brand purchaser is much greater for the test group than for the control group (0.176 versus −0.375). The difference between the test and control groups is significant at the 0.01 level using a *t*-test. Overall, we find that the total incremental sales (i.e., the difference in volume between test and control groups) in the postperiod represents an increase of 18% over the prepromotion period, after adjusting for the unequal sample sizes in the two groups and for any preperiod differences in brand sales volume.

The difference between the test and control groups over time can be observed in Figure 1, which shows the cumulative difference in sales volume per 1,000 households. For ease of comparison, the data in Figure 1 have been adjusted to correct for the small difference in brand sales between the test and control groups in the prepromotion period.[6] During the 52 prepromotion weeks the test and control groups show very similar levels of purchasing. Beginning in week 53, when the free sample was delivered, the test group shows a steady increase in purchasing relative to the control group. Note that if the sales increase had been temporary, the cumulative difference between the groups would have stabilized at a constant level and the curve would have flattened out as it typically does in the case of coupon promotions (e.g., see Klein 1981). However, in this test the cumulative difference does not stabilize and continues to increase over the 52 weeks following the promotion. Thus the promotion's effect on purchasing was sustained for at least 12 months after the delivery of the free sample.

The relatively long-term effect of the free sample promotion—12 months or more—is in sharp contrast to the effects of many other consumer promotions. For example, the incremental sales effect of a coupon promotion tends to occur within the first 12 weeks after the promotion (Klein 1981), while the impact of cents-off retailer price promotions does not appear to last much beyond the period of the price reduction (Guadagni and Little 1983). Thus the observed effect of the free sample promotion 12 months after the promotion suggests a relatively long-term impact compared with other consumer promotions, such as coupons or temporary price cuts.[7]

A question that arises is whether the long-term increase is mainly due to households who had tried the brand before the promotion (i.e., Segment 1 in our model) or to new triers. Our analysis shows that among prior triers the average purchase probability for the subject brand increased slightly in both test and control groups during the postperiod, with the increase being marginally greater (by 0.01) in the

[6] The adjustment is done as follows. We first compute the average difference in brand sales between test and control groups during the preperiod (weeks 1–52). We then subtract this average weekly difference in sales from the observed difference in sales for each of the 104 weeks. Figure 1 shows the cumulated values of these adjusted differences. This form of adjustment is suggested for Before-After with Control Group experiments (e.g., Green and Tull 1978) and is similar to that used by Klein (1981).

[7] A number of additional analyses (not reported here for brevity) supported this conclusion. For example, we examined the probability of purchasing the sampled brand on three purchase occasions immediately prior to the sample delivery and three purchase occasions immediately following the delivery. This analysis was done for all households that ever purchased the brand in the 104-week period. Our results showed that the probability of purchasing the brand in the free sample group was 6.8%, 5.6%, and 7% on the three purchases prior to the sample delivery and 10.1%, 9%, and 9.5% on the three postpromotion purchases. If the free sample had only a short-term effect we would expect to see an increase in the brand's purchase probability on the first occasion after the delivery and a decline to the prepromotion probability on subsequent occasions. It appears, however, that the effect of the free sample tends to be sustained for several purchase occasions.

test group. We conclude from this that the long-term impact of the promotion was mainly due to new triers in Segments 2 and 3.

Experiment 2

Experiment 2 was conducted by a different manufacturer in the same category. The management's objective was to compare the effectiveness of three different consumer promotions (two types of direct mail coupons and one free sample with coupon) relative to a control group. Experiment 2 differs from Experiment 1 in the following respects.

(a) The new brand being promoted and tested is a variation on a well-established brand in the category, and it had considerably lower sales than the original brand. In the 1-year period prior to the promotion, fewer than 5% of the households in our sample had purchased the new brand.

(b) The free sample consisted of a regular full-size package and contained enough product for several usage occasions.

The four treatment groups and sample sizes were as follows:

Group 1 (Solo Coupon) received a $1.50 coupon, mailed via first class as a solo mailing with an 8.5-inch by 11-inch insert similar to an FSI advertisement ($n = 1{,}629$ households).

Group 2 (Postcard Coupon) received a $1.50 coupon on one side of a postcard ($n = 1{,}076$).

Group 3 (Free Sample/Coupon) received a free sample (full-size package) and a $0.50 coupon ($n = 457$).

Group 4 (Control) did not receive any promotion at this time ($n = 1{,}718$).

The total sample size for the four groups is 4,880 households. As in the previous experiment, we formed a static sample consisting of households that had made at least one product class purchase in each 6-month period of the data. The coupons in Groups 1, 2, and 3 could only be redeemed for the new brand. In addition, sales of the new brand were less than 20% of the sales for the total brand (original plus new). As a result of these two factors, we primarily focused on the sales of the new brand in this experiment. However, as a check, we also examined the sales of the total brand. We were not able to observe any significant effects for any of the three promotions on sales of the total brand, because the increase in sales of the new brand is very small relative to the weekly variation in sales for the original brand. The four panels were matched to have roughly equal levels of brand and product class sales per household in the year prior to the promotion tests.

Results

The total impact of the free sample promotion in Experiment 2 is also positive. However, the effect of this free sample promotion appears to end after about 22 weeks. While this duration is much greater than that for a typical coupon promotion, it is not as long as the duration in Experiment 1.

Table 2 **Experiment 2: Average Change in Volume per Trier Household**

Group	Average change in volume[a]	No. of triers (percent in group)[b]
Solo coupon	0.660[c] (0.149)	229 (14%)
Postcard coupon	0.475[c] (0.187)	110 (10%)
Free sample and coupon	0.528[c] (0.353)	59 (13%)
Control	−0.011[c] (0.128)	141 (8%)

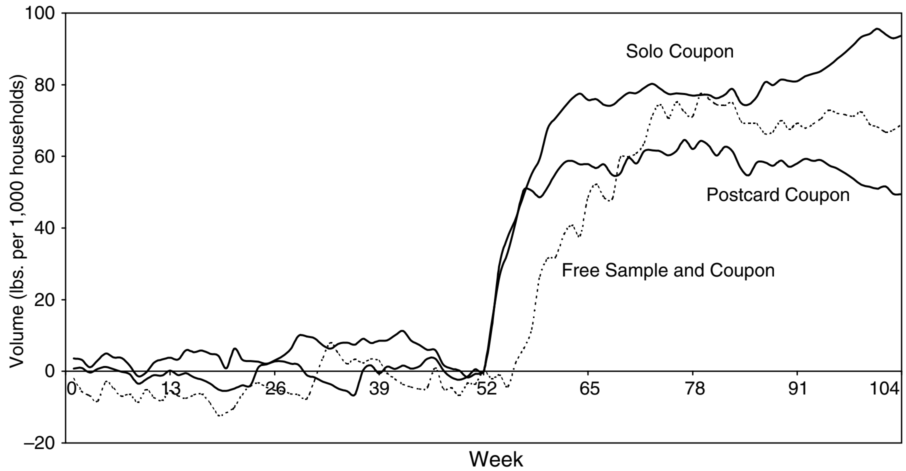
[a] Standard errors are in parentheses.
[b] Number and percent of households who purchased the brand at least once in the 2-year period.
[c] Change in total volume is significantly different across groups ($p < 0.05$) based on an F-test.

Table 2 shows that the change in sales volume per brand purchaser varies across treatments. It is higher for the three sales promotions (solo coupon, free sample with coupon, and postcard coupon) than for the control group. The null hypothesis that all four means are equal can be rejected at the 0.05 level with an F-test. Overall, we find that the total incremental sales due to the free sample promotion (i.e., the difference in volume between the free sample with coupon, and control groups) in the postperiod represents an increase of 93% over the prepromotion period, after adjusting for the unequal sample sizes in the two groups and the trend in the preperiod. Although this seems to indicate that the promotion in Experiment 2 had a large impact on sales, it is important to keep in mind that the increase is relative to baseline sales of a new variant of the brand, which were quite low compared with the sales of the total brand (original plus new variant). Compared with Experiment 1, the promotion in Experiment 2 had a smaller impact on a per household basis because of the relatively small number of buyers of the subject brand. The average incremental volume per household in Experiment 1 was 0.208 units, about three times the average (0.069 units per household) in Experiment 2 (see Figures 1 and 2).

An additional indicator of the promotion's effectiveness is the number of new trials (i.e., households making a first purchase of the brand) generated by the promotion. In Experiment 1 we found that the number of incremental trials produced by the promotion was 28 per 1,000 households, while in Experiment 2 the number of incremental trials was 17 per 1,000.[8]

[8] The observed number of first purchases in Experiment 1 was 566 and 570 during the preperiod and 177 and 266 during the postperiod in the control and test groups, respectively. In Experiment 2

Figure 2 **Experiment 2: Adjusted Cumulative Difference (Test-Control) in Total Volume Per 1,000 Households**



This is consistent with our finding of a higher incremental volume per household in Experiment 1, and suggests that the promotion in Experiment 1 was more effective overall.

Figure 2 shows the cumulative difference (test minus control) in sales per household for Experiment 2. Several observations can be made based on the figure.[9] First, both coupon promotions produced an increase in sales starting in week 53, the week of the coupon deliveries. In contrast, the difference in sales for the free sample promotion did not increase until week 56, a delay of 4 weeks. This may reflect the fact that the free sample in Experiment 2 was a full-size package, rather than the single-serving package distributed in Experiment 1.

Second, the durations of the promotional effects differed. It appears that the effects of the coupons wore out within about 12 weeks, to be followed by a period of instability.[10] This is highly consistent with the results reported by Klein (1981) for coupons. In contrast, the positive effects of the free sample promotion appear to last from week 56 to about week 74, or 19 weeks.

the number of first purchases in the control and test groups was 79 and 28 during the preperiod and 62 and 31 during the postperiod. These observations were converted to a per 1,000 basis, and the number of incremental trials in each experiment was estimated as (test(post) – control(post)) – (test(pre) – control(pre)).

[9] Although the purchase share of the new brand was the same in the free sample and control groups during the preperiod, its sales volume per household was somewhat lower in the control group than in the test groups (1, 2, and 3) during the preperiod. As in Experiment 1, the difference in weekly sales between each test group and the control was adjusted by the average difference in sales between those groups during the preperiod (weeks 1–52).

[10] During weeks 91 to 101, the cumulative difference in sales for the solo coupon group increased for reasons that are not clear. This increase appears to be unrelated to the promotion, and was not observed in the other treatment groups.

Model Parameter Estimates for Experiments 1 and 2

The above aggregate-level analyses and the plots in Figures 1 and 2 prompt us to consider why there were differences in impact between Experiment 1 and Experiment 2, and what might be learned about ways to improve the effectiveness of free sample promotions. The ACE model provides a basis for understanding the process that might be driving the aggregate difference in sales between the test and control groups. In particular, we can use the model to simulate the purchase behavior of Segment 1, 2, and 3 consumers with respect to the subject brand, to predict the impact of the free sample promotion in terms of generating incremental volume, and to decompose the overall incremental sales into the acceleration, cannibalization, and expansion components.

In this section, we estimate the parameters in Equation (10) using the data from the two experiments, and discuss the implications of the parameter estimates for the effectiveness of the free sample promotions in the two experiments.[11] Maximum likelihood estimates for the parameters are obtained as described in Appendix C. The resulting estimates of model parameters, and the estimated average trial and repeat purchase probabilities, are presented in Table 3.[12] By substituting the parameter values into

[11] Although the free sample promotions in the two experiments included coupons with the samples, the coupons appeared to have little impact on incremental volume. In Experiment 1, all but 14 of the test coupons were redeemed by households that had purchased the brand earlier. In Experiment 2, only five of the test coupons were redeemed. Therefore we estimate the base model (Equation (10)) rather than the extended model (Equation (12)).

[12] As noted earlier, the free sample in Experiment 2 was a full-size package. While the estimation procedure in Appendix C is not affected by this difference, the predicted difference in sales (D in Equation (10)) must be adjusted to a lower value, as shown in Appendix A.

Table 3 Model Parameter Estimates for Experiments 1 and 2

Model parameters	Description	Estimate[a] Experiment 1	Experiment 2
α_0	Distributional parameter for trial probability t_{2j}	0.74 $(7.1 \cdot 10^{-9})$	0.45 $(2.8 \cdot 10^{-8})$
β_0	Distributional parameter for trial probability t_{2j}	25.07 $(5.7 \cdot 10^{-8})$	25.20 $(2.3 \cdot 10^{-7})$
α_1	Distributional parameter for posttrial purchase probability r_{1j}	0.94 (0.10)	0.30 (0.07)
β_1	Distributional parameter for posttrial purchase probability r_{1j}	11.96 (1.81)	8.61 (3.46)
α_2	Distributional parameter for posttrial purchase probability r_{2j}	0.68 (0.19)	0.30 $(7.8 \cdot 10^{-7})$
β_2	Distributional parameter for posttrial purchase probability r_{2j}	12.64 (4.59)	25.24 $(8.1 \cdot 10^{-6})$
α_3	Distributional parameter for posttrial purchase probability r_{3j}	0.18 (0.05)	0.06 (0.02)
β_3	Distributional parameter for posttrial purchase probability r_{3j}	25.24 (7.94)	15.53 (5.28)
t_2	Average trial probability (Segment 2)	0.029	0.017
r_1	Average posttrial purchase probability (Segment 1)	0.073	0.034
r_2	Average posttrial purchase probability (Segment 2)	0.051	0.012
r_3	Average posttrial purchase probability (Segment 3)	0.007	0.004
n_1	No. of households—Segment 1	570	28
n_2	No. of households—Segment 2	192	22
n_3	No. of households—Segment 3	1,297	407
N	Total no. of free sample recipients (households in test group)	2,059	457

[a] Standard errors are in parentheses (where applicable).

Equation (10) we also estimate the theoretical or predicted level of incremental sales for each experiment. These estimates, which are based on the observed average number of product class purchases (K) in the postperiod by test group households, are shown in Table 4.

There are several aspects of the parameter estimates shown in Table 3 that suggest they have high face validity.[13] First, in both experiments Segment 1 has the highest average purchase probability and Segment 3 the lowest (i.e., $r_1 > r_2 > r_3$). This is consistent with expectations, because Segment 1 households began purchasing the brand earlier than other households in the sample, and Segment 3 households, by assumption, are the least likely to buy the brand. Second, we see that the subject brand in Experiment 1 enjoys higher trial and repeat purchase probabilities compared with the subject brand in Experiment 2. This is consistent with the fact that the brand in Experiment 1 has a higher market share in our data.

Brands with a higher market share would normally stand to benefit less from a free sample promotion, other things being equal, since there are fewer nontriers (Segment 3 members) that could be converted to buyers. However, as can be seen in Table 4, the theoretical or predicted level of incremental sales is greater in Experiment 1 than in Experiment 2 on a per-household basis (D^* per 1,000 in Table 4). The parameter estimates in Table 3 give us some insights into these observations.

First, we can see that the subject brand in Experiment 1 has nearly twice the proportion of households in Segment 2 and a brand purchase probability in this group that is four times higher ($n_2/N = 0.09$ and $r_2 = 0.051$) than the brand in Experiment 2 ($n_2/N = 0.05$ and $r_2 = 0.012$). This results in a substantially greater acceleration effect in Experiment 1. In other words, brand sales were increased significantly by speeding up purchasing among likely triers.

Second, in Experiment 1 the average posttrial purchase probability is greater than the average trial probability among Segment 2 households ($r_2 > t_2$), whereas the opposite is true in Experiment 2 (i.e., $r_2 < t_2$). The implication is that the brand in Experiment 2 is less effective in retaining customers after trial. In addition, when $r_2 < t_2$, it takes many purchase occasions for the gain in sales from acceleration to compensate for the loss of trial purchases among Segment 2 households. Consequently, net incremental sales from Segment 2 tend to be low or negative in such situations. This reduces the incremental sales from the promotion in Experiment 2.

Third, the subject brand in Experiment 1 enjoys a higher average purchase probability ($r_3 = 0.007$) among Segment 3, i.e., nontriers, than in Experiment 2 ($r_3 = 0.004$). This implies that in Experiment 1 more people who would not otherwise have purchased the brand were induced to do so by the free sample promotion.

To summarize, we can see that the promotion in Experiment 1 was more successful on a per household basis because of a larger potential for acceleration of purchases, greater retention of customers after trial, and a higher purchase probability among those who would not have tried the brand without a free sample. However, the promotion in Experiment 2 led to a larger increase in sales relative to the preperiod

[13] To test the stability of the estimates, a large number of runs were made with different starting values. The final estimates of the parameters were highly consistent over these tests.

Table 4 Theoretical Incremental Sales Estimates For Experiments 1 and 2 Based on the Model

Incremental sales measures	Description	Estimate[a] Experiment 1	Experiment 2
Acceleration	Incremental sales due to acceleration	204	8
Cannibalization	Incremental sales due to cannibalization	−82	−7
Expansion	Incremental sales due to expansion	263	62
D	Total incremental sales volume (see Equation (10))	384	63
Adj	Adjustment for full-size free sample (see Appendix A, Equation (A.1))	N.A.	3
D^*	Net incremental sales volume (see Appendix A)	384	60
D^* per 1,000	Net incremental sales volume per 1,000 households[b]	186	131

[a] Based on Equation (10), using the estimated model parameters and the observed average number of product class purchases (K) per household in the test group for each experiment.

[b] The number of free sample recipients in Experiments 1 and 2 were 2,059 and 457, respectively. Estimates of D^* were adjusted accordingly.

because of the brand's smaller initial customer base and larger proportion of nontriers of the brand in the population.

The preceding analyses show that free sample effects can be fairly complex and that the model can be helpful in unraveling this complexity and understanding the different factors involved. Next, we use the parameter estimates to compare the theoretical or predicted level of D from the model, as shown in Table 4, to the observed differences in cumulative sales. For purposes of this comparison we use the unadjusted observations of incremental sales (i.e., unadjusted for preperiod differences between test and control groups), because the model parameters were estimated on the unadjusted data. These unadjusted observations of incremental sales are 168 and 184 units, respectively, in Experiments 1 and 2.

As can be seen in Table 4, for Experiment 1 the theoretical estimate of incremental volume is 186 units, which is within 11% of the actual value. For Experiment 2, the theoretical estimate is 131 units, which is 29% less than the actual value. The estimate for Experiment 1 is closer to the observed difference D than for Experiment 2. This could be due to the fact that the sample sizes in Experiment 2 are much smaller than those in Experiment 1 (457 versus 2,059 in the free sample treatment groups), leading to greater sampling error in our estimates of incremental sales and purchase probabilities.

Although the magnitude of incremental sales and the number of trials generated by the free sample promotion are important measures of its impact, the source of incremental sales is also important in assessing the promotion's effectiveness. We can see from Table 4 that the main source of incremental sales in Experiment 2 is the expansion effect, whereas in Experiment 1 both the expansion and acceleration effects contribute about equally to the total impact of the promotion. An important implication of this is that whereas free sample promotions for new or low-share brands must depend on the expansion effect (i.e., converting those who would not otherwise try the brand) for incremental sales, established or larger-share brands can benefit both from expansion effects on nontriers and acceleration effects on likely triers.

A number of conclusions about free sample effectiveness might be drawn from these analyses. First, repeat purchase probabilities among those who have not tried the brand (i.e., Segment 2 and 3 consumers) are critical to the free sample promotion's effects. Second, more-established or larger-share brands could be at a disadvantage when running free sample promotions because there are fewer nontriers left to convert. However, the higher repeat purchase probabilities that they might enjoy compared with smaller-share brands might compensate for this. Insights such as these could be used by managers to identify brands that could be promoted more effectively via free sample promotions.

It should be noted that all the parameters in Table 3 other than α_3 and β_3 could be estimated from scanner data for the product class and would not require distribution of the free sample.[14] Estimates for α_3 and β_3 could be made in several ways in advance of the free sample promotion. First, one could conduct a laboratory test (see Silk and Urban 1978) to determine consumer reactions to the free sample as a basis for

[14] Segment 1 and 2 parameters are estimated using data from households that do not receive a free sample. Parameters α_0 and β_0 for the trial probability are estimated from data on trial purchases, while (α_1, β_1) and (α_2, β_2) are estimated using posttrial purchase data from households that made at least one purchase of the brand. See Appendix C.

estimating α_3 and β_3. In particular, by surveying subjects after they have tried a free sample in the lab, one could estimate α_3 and β_3 among those who state they would have been unlikely to try this brand without being given a free sample. Second, if a number of experiments on free samples are conducted, one could see the range of r_3 values that are estimated and use these as benchmarks for estimating r_3 prior to the actual free sample promotion. Finally, because $r_1 > r_2 > r_3$, we can use r_2 as an upper bound for r_3. This would also be consistent with data from coupon studies showing that the average repeat rates are lower among those who make a prior purchase of the same brand with a coupon, relative to those buying without a coupon (Dodson et al. 1978). We would expect this same phenomenon to hold for free samples.

The potential value in using a model along with data from the controlled experiments can be further illustrated by sensitivity analyses conducted for different "what if" scenarios. In the following analyses, we use the model parameters estimated from the data in Experiment 1, estimate the theoretical value of incremental sales (i.e., D from Equation (10)) after 100 periods, and examine how this quantity would be affected if the parameters were changed in specific ways by managerial actions. According to the model, given the parameter estimates for Experiment 1, the incremental sales after 100 periods due to acceleration, cannibalization, and expansion are 488, −134, and 938, respectively, and the total is 1,292 units.

First, we consider the case where the brand choice probabilities r_2 and r_3 for Segments 2 and 3 are increased by 10%. This might be accomplished by altering the product or packaging, or by repositioning the brand. The total incremental sales after 100 periods is 1,426, or an increase of 10.4%. This increase is due to greater expansion and acceleration effects. The level of cannibalization is unchanged.

Next, we consider the impact of an increase in the α_0 parameter that increases the trial probability by 10% among those in Segment 2. This higher trial rate might result from increased advertising or more in-store displays. The effect of this is to leave the expansion term unaffected and to cause a small decrease in acceleration and a slight increase in cannibalization, resulting in a net decrease of 2.7% in incremental sales.

We consider next what would happen if the number of households in Segments 1 and 2 were 10% higher (as of $K = 0$) and the number of households in Segment 3 were reduced by the same number. This might come about if the firm was using a higher level of advertising, pricing at lower levels, or using more coupons prior to the free sample promotion (Narasimhan 1984). Under these circumstances, the level of incremental sales due to expansion is reduced, but the number of accelerated purchases is increased. The total incremental sales would decrease by 1.4%.

Finally, we examine what would happen if the number of households in Segment 1 (i.e., prior triers) was reduced by 10% from 570 to 513 households, and the number in Segment 2 was increased. This might be the case for a smaller-share brand, or if there were fewer coupon promotions or higher prices prior to the free sample promotion. This change produces a net increase of 8.2% in total incremental sales, has no effect on expansion sales, and increases both the level of acceleration and the level of cannibalization because there are now more households in Segment 2, i.e., more likely triers.

In summary, it is possible for a brand manager to examine the impact of different marketing strategies by using the model in conjunction with parameters estimated from one particular controlled experiment. In this study, the parameters were estimated from large-scale controlled experiments. In future applications, however, the parameters might be estimated from laboratory experiments or specified by the analyst as in decision support models for trade and consumer promotions.

Conclusions

This study presents a model of how a free sample promotion is expected to affect the various components of incremental sales. The paper also compares the actual differences in sales between the free sample and control groups for two controlled field experiments. We found that the promotion had a positive effect on incremental sales in both experiments; although the free sample in Experiment 2 had a greater impact relative to the preperiod sales, the promotion's effect was bigger in Experiment 1 on a per-household basis. The model in conjunction with the parameter estimates obtained for the two experiments indicate that a number of factors accounted for the bigger impact of the promotion in Experiment 1. These factors included greater retention of customers after trial, a larger potential for acceleration of purchases, and a higher purchase probability among those who would not have tried the brand without a free sample.

This study is one of the first to show that free samples can be highly effective in increasing sales over a long period. The free sample promotions in this study increased sales for 22 weeks or longer in the test group relative to the control group. While this might be expected, we are not aware that this effect has been demonstrated in any prior studies on sampling. As further evidence is published, a clearer picture of free sample effects can be obtained.

It is recognized that most product managers will be considering the use of free sample promotions in product categories that have different levels of purchase frequency, concentrations of market share, and brand loyalty than in this study. Despite these differences, it appears that several useful insights can be gained both from the empirical findings and from the model development.

A major finding of our study is that for some products the effects of free sample promotions can persist for at least 52 weeks. In contrast, the effects of other consumer promotions such as coupons tend to last for no more than 12 weeks. This is an important finding for managers whose objective is to produce a long-term increase in sales. This could be a particularly important benefit for smaller-share brands. Such brands have relatively few users and therefore might not get a large response to a coupon promotion. At the same time, these brands are unlikely to be purchased by most households without a promotion. In such situations, free sample promotions might be highly effective as a basis for generating incremental sales and building a brand franchise.[15] In addition, free samples might help build loyalty if consumers favor sampled brands over other brands that they have not tried (Villas-Boas 2004).

We also found that the effectiveness of free samples can vary widely, even between two brands in the same product category. In this study, the free sample promotion for the smaller-share brand depended largely on an expansion effect for incremental sales, while the larger-share brand generated incremental sales through both expansion and acceleration effects. Larger-share brands might be at a disadvantage when running free sample promotions because of the fewer nontriers left to convert, but if they have higher repeat purchase probabilities than smaller-share brands this disadvantage might be reduced.

Several other applications of the model can be visualized that would be relevant for managers of other brands. For example, if one supplies parameter estimates for the model for different brands in other product categories, one could estimate the dynamic impact of the expansion, cannibalization, and acceleration effects. Our model suggests that free sample promotions would be most effective when the sizes of Segments 2 and 3 were large, the trial probability was low, and the brand choice probability following trial was expected to be high. In addition, the model predicts that the number of incremental purchases per year will increase as the average number of product class purchases per year increases. As a result, the model predicts that free samples will be more effective for brands within frequently purchased product classes.

[15] We thank Scott Neslin for suggesting this point.

Heterogeneity in purchase frequency and correlation between purchase frequency and brand purchase probability are included in the current simulation model. In the future, it might be helpful to include these factors in the base model. Extending the model to predict the number of new trials generated by the promotion might represent another useful development. Finally, although the model has been developed for analyzing the impact of free sample promotions, it could be modified for use with other types of promotions, such as coupons and mail-in rebates. Using the model to analyze the incremental sales impact of a promotion and to decompose it into acceleration, cannibalization, and expansion components can be helpful in understanding the nature and future impact of the promotion on sales.

Several additional issues remain to be addressed in future studies. First, what factors determine whether or not consumers use the free sample? Although usage of free samples appears to be high compared with usage of other consumer promotions such as coupons alone (Sunflower Group 1997), little is currently known about the brand and consumer characteristics that are related to this behavior. Second, what are the key determinants of the brand choice probabilities following usage of a free sample?

While our initial results are encouraging, we have been able to locate data for only two large-scale controlled experiments. In addition, the sampled brands in both experiments were line extensions of existing brands. More empirical work is needed to determine whether the findings generalize to other product categories and for completely new brands. Given the widespread use of this type of promotion and the relative paucity of empirical analyses of its effects, it is our hope that more data will become available to enable researchers to arrive at a more comprehensive understanding of sampling.

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Appendix A. Modification of Model if Free Sample Is a Full-Size Package

The initial derivation of Equation (10) is based on the assumption that the free sample is a small quantity and is much smaller than a standard package size. However, in some cases, firms might distribute a full-size box or bottle of the product. The effect of this full-size free sample on Segments 1, 2, and 3, relative to a trial-size free sample, can be estimated as follows:

Consider the n_1 households in Segment 1. After usage of the free sample, the probability of household j buying the brand is r_{1j}. If the free sample is a full-size package, these households now have one fewer opportunities to buy the product class. Thus, the expected number of lost purchases from this group on one purchase occasion is $n_1 r_1$. Similarly, the expected number of lost purchases from Segments 2 and 3, relative to the case of a trial size free sample, are given by $n_2 r_2$ and $n_3 r_3$, respectively. The net adjustment (*Adj*) to sales is given by the sum of the lost purchases for the three segments:

$$Adj = n_1 r_1 + n_2 r_2 + n_3 r_3. \quad \text{(A.1)}$$

Thus the adjusted level of incremental sales will equal D in Equation (10) minus the adjustment *Adj*. While this seemingly makes the level of incremental sales smaller, the larger free sample size might result in different purchase probabilities r_2 and r_3 than if a small sample was delivered. For simplicity, in the derivation of Equation (10) we have assumed that the values of r_2 and r_3 are unaffected by the size of the free sample.

Appendix B. Simulation Model Details

A simulation model was programmed to answer several questions about the impact of heterogeneity in product class purchase probability (PCPP) that could not be answered directly with the closed form model in Equation (10). The simulation worked as follows:

1. We selected values for the parameters in the model (Equation (10)). These included parameters such as the sample sizes (n_i) and parameters for the beta distributions (α_i and β_i). The parameter values used for most of the simulations were those estimated from the field experiment data. These values are shown in Table 3. Sample sizes of 566, 196, and 1,297 households in Segment 1, 2, and 3, respectively, were used in the simulations.
2. Random draws were made from the beta and other distributions to determine the trial, brand choice, and other probabilities for each household in the simulation.
3. The stochastic purchasing behavior for each household in each period was simulated over K periods. This was done for the condition when a free sample promotion was offered and also when it was not. The difference in sales of the subject brand between the promotion and no promotion conditions was computed to determine the simulated value of D and the three components of D in Equation (10) for each period.
4. The first analysis conducted was to determine whether the values of D were affected if we introduced heterogeneity (across households) in the probability of buying the product class. In the base case, each household was assigned a probability of 0.5 of buying the product class in each period. In the heterogeneous case, the probability of buying the product class for each household was drawn from a uniform distribution between 0 and 1. We found that this had only a small effect on the simulated values of D. The simulated value of D for the heterogeneous case was only 0.7% less than the value for the homogeneous case. In addition, the three components of D were also not sensitive to this change. We conclude that the predictions from the model are not highly sensitive to the assumption that product class purchase rates are assumed to be homogeneous, provided these rates are not correlated with brand choice probabilities.
5. A second analysis was conducted to determine how the values of D and its components were affected if we induced a positive or negative correlation (across households) between the brand choice probabilities (r_{ij}) and the probability of purchasing the product class (PCPP) in any given period. Correlation was introduced as follows: First, we simulated a base case with a single beta distribution ($\alpha_2 = 0.197$, $\beta_2 = 4.588$) for brand purchase probability r_{2j} in Segment 2. This distribution was then replaced by two beta distributions ($\alpha_2 = 7$, $\beta_2 = 120$ and $\alpha_2 = 3.36$, $\beta_2 = 120$). The mean of two betas ($(0.0551 + 0.0272)/2$) equals the mean of the first beta (0.197/4.785 or 0.0411). We then performed a median split based on the probability that a given household would make a purchase of the product class in any given period. If a household was above the median, then the probability of buying the subject brand (r_{2j}) was drawn from the beta with the higher mean for a positive correlation. If a household was below the median, r_{2j} was drawn from the beta distribution with the lower mean. The opposite was done to induce a negative correlation. A similar procedure was used for Segment 3. The results showed that a positive correlation led to a greater incremental sales effect of the promotion, while a negative correlation had the opposite effect.
6. A third analysis was conducted to determine the effect of a positive correlation between the trial purchase probabilities t_{2j} and the brand choice probabilities following trial (r_{ij}). Using a method similar to that in the preceding analysis, we induced a correlation of 0.3 between these two variables. The overall effect of the promotion was reduced by 10.7%.

Appendix C. Estimation of Model Parameters

Estimation of Segment Sizes n_1, n_2, and n_3

Let λ be the proportion of the population in Segments 1 and 2 combined. By definition, Segment 1 households have tried the brand and all members of Segment 2 will eventually try the brand without being given a free sample. Therefore an estimate of λ can be obtained from the percent of households in the control group (i.e., who do not receive a free sample) who are expected eventually to try the brand. This percent is estimated by plotting the cumulative percent of the sample over time that makes at least one purchase of the brand and estimating the asymptotic percent of triers in the group. This yields estimates of $\lambda = 0.37$ for Experiment 1 and $\lambda = 0.11$ for Experiment 2. Estimates of the size of Segments 1 and 3 in the test group are then obtained as $n_3 = (1 - \lambda)N$ and $n_1 =$ the number of triers in the test group prior to the promotion, where N is the sample size in the test group. The size of Segment 2, n_2, is then estimated as $n_2 = N - n_1 - n_3$.

Estimation of Trial Probability Parameters

By definition, households that have not tried the brand prior to the promotion are members of either Segment 2 or Segment 3. The trial probability for household j in Segment 2 is t_{2j}, while Segment 3 households have a zero probability of making a trial purchase of the brand in the absence of sampling. Let us assume that we are dealing with a heterogeneous population of households and that t_{2j} is distributed within Segment 2 as Beta(α_0, β_0). Let $Y_j = 1$ if household j makes a trial purchase, and $Y_j = 0$ if not. First, consider the set of households that make a trial purchase in the absence of a free sample promotion. Suppose we observe that household j makes $K_j - 1$ purchases of other brands, followed by a trial purchase. Let $\lambda_2 = n_2/(n_2 + n_3)$ be the probability that this household belongs to Segment 2 and $(1 - \lambda_2)$ that it belongs to Segment 3. The conditional probability of the household making a trial purchase, given membership of Segment 3, is zero. Therefore the likelihood of observing this particular sequence of data is

$$L(Y_j = 1) = \lambda_2 \int (1 - t_{2j})^{K_j - 1} t_{2j} f(t_{2j})\, dt_{2j}. \qquad \text{(C.1)}$$

Because $f(t_{2j}) \sim \text{Beta}(\alpha_0, \beta_0)$, this becomes

$$L(Y_j = 1) = \lambda_2 \frac{\Gamma(\alpha_0 + \beta_0)\Gamma(\alpha_0 + 1)\Gamma(\beta_0 + K_j - 1)}{\Gamma(\alpha_0)\Gamma(\beta_0)\Gamma(\alpha_0 + \beta_0 + K_j)}. \qquad \text{(C.2)}$$

We now consider the set of households that make no purchases of the subject brand. Suppose we observe household j that makes K_j purchases of other brands and no purchases of the subject brand. This household could come from Segment 2 with probability λ_2 and from Segment 3 with probability $(1 - \lambda_2)$. Because the probability of observing no trial, given membership of Segment 3, is unity, the likelihood of observing this particular sequence is given by

$$L(Y_j = 0) = \lambda_2 \int (1 - t_{2j})^{K_j} f(t_{2j})\, dt_{2j} + (1 - \lambda_2), \qquad \text{(C.3)}$$

which reduces to

$$L(Y_j = 0) = \lambda_2 \frac{\Gamma(\alpha_0 + \beta_0)\Gamma(\beta_0 + K_j)}{\Gamma(\beta_0)\Gamma(a_0 + \beta_0 + K_j)} + (1 - \lambda_2). \qquad \text{(C.4)}$$

The log-likelihood of observing the data for all households in the sample is given by

$$L_0^* = \sum_j Y_j \ln L(Y_j = 1) + \sum_j (1 - Y_j) \ln L(Y_j = 0). \qquad \text{(C.5)}$$

Given λ_2, estimates of (α_0, β_0) are obtained by maximizing L_0^* with respect to these parameters. Data from households in the control group are used to estimate these parameters. These panel members did not receive a free sample and thus can be used to estimate the trial probability in the absence of a free sample. In order to ensure that the first purchase we observe is a trial purchase, we use data from households in the control group that did not purchase the brand in year 1. Thus the first purchase of the brand in year 2, if any, made by a household in this group is assumed to be a trial purchase for the household.

The log-likelihood function in (C.5) was maximized using the NLP procedure in SAS (1999).

Estimation of Repeat Purchase Probability Parameters

As in the case of the trial probability, we assume within-segment beta heterogeneity in the purchase probabilities r_{1j}, r_{2j}, and r_{3j}. That is, $f(r_{1j}) \sim \text{Beta}(\alpha_1, \beta_1)$, $f(r_{2j}) \sim \text{Beta}(\alpha_2, \beta_2)$ and $f(r_{3j}) \sim \text{Beta}(\alpha_3, \beta_3)$ within Segments 1, 2, and 3 respectively. These parameters are estimated using maximum likelihood as described next. In all cases the NLP procedure in SAS was used for maximization.

Segment 1 Parameters. Parameters for Segment 1 are estimated using data from households in the control group that purchased the brand at least once in the preperiod. To ensure that only posttrial purchases are included, we ignore the first purchase for each household in this analysis. Let n_j denote purchases made by household j following the first purchase in the data, and x_j of these are of the subject brand. The likelihood of observing this sequence is given by

$$L_{1j} = ({}^{n_j}C_{x_j}) \int (r_{1j})^{x_j} (1 - r_{1j})^{n_j - x_j} f(r_{1j})\, dr_{1j}. \qquad \text{(C.6)}$$

Ignoring the combinatorial constant because it does not affect the maximization of the likelihood function, this can be written as

$$L_{1j} = \frac{\Gamma(\alpha_1 + \beta_1)\Gamma(\alpha_1 + x_j)\Gamma(\beta_1 + n_j - x_j)}{\Gamma(\alpha_1)\Gamma(\beta_1)\Gamma(\alpha_1 + \beta_1 + n_j)}. \qquad \text{(C.7)}$$

Estimates of (α_1, β_1) are obtained by maximizing the log-likelihood function, given by

$$L_1^* = \sum_j \ln L_{1j}. \qquad \text{(C.8)}$$

Segment 2 Parameters. These parameters are estimated using data from households in the control group who did not purchase the brand in the preperiod, but that purchased it at least once in the postperiod. By definition, Segment 3 households in the control group would not purchase the brand, and therefore are not part of this sample of households. The first purchase for each household is ignored to ensure that only posttrial purchases are included in this analysis. As earlier, the likelihood of observing a sequence of x_j purchases of the subject brand out of n_j product category purchases can be written as

$$L_{2j} = \frac{\Gamma(\alpha_2 + \beta_2)\Gamma(\alpha_2 + x_j)\Gamma(\beta_2 + n_j - x_j)}{\Gamma(\alpha_2)\Gamma(\beta_2)\Gamma(\alpha_2 + \beta_2 + n_j)}. \qquad \text{(C.9)}$$

The log-likelihood function is then maximized to obtain estimates of (α_2, β_2):

$$L_2^* = \sum_j \ln L_{2j}. \qquad \text{(C.10)}$$

Segment 3 Parameters. Parameters for Segment 3 are estimated using data from the test group following delivery of the free sample. We assume that all households in the test group were exposed to the subject brand as a result of receiving the free sample, and that any purchases of the brand made after that point in time are posttrial purchases. The analysis includes only households that had not purchased the brand in the preperiod, yielding a sample of households that is a mix of Segment 2 and Segment 3.

Let $\lambda_2 = n_2/(n_2 + n_3)$ be the probability that a household in this sample belongs to Segment 2 and $(1 - \lambda_2)$ the probability that it belongs to Segment 3. Suppose we observe household j making n_j product class purchases following the free sample delivery, and x_j of these are of the subject brand. Because this household could come from Segment 2 or Segment 3, the likelihood of observing this sequence is given by

$$\begin{aligned} L_{3j} = {} & \lambda_2 ({}^{n_j}C_{x_j}) \int (r_{2j})^{x_j} (1 - r_{2j})^{n_j - x_j} f(r_{2j})\, dr_{2j} \\ & + (1 - \lambda_2)({}^{n_j}C_{x_j}) \int (r_{3j})^{x_j} (1 - r_{3j})^{n_j - x_j} f(r_{3j})\, dr_{3j}. \end{aligned} \qquad \text{(C.11)}$$

This can be written as

$$L_{3j} = \lambda_2 \frac{\Gamma(\alpha_2+\beta_2)\Gamma(\alpha_2+x_j)\Gamma(\beta_2+n_i-x_j)}{\Gamma(\alpha_2)\Gamma(\beta_2)\Gamma(\alpha_2+\beta_2+n_j)} + (1-\lambda_2)\frac{\Gamma(\alpha_3+\beta_3)\Gamma(\alpha_3+x_j)\Gamma(\beta_3+n_j-x_j)}{\Gamma(\alpha_3)\Gamma(\beta_3)\Gamma(\alpha_3+\beta_3+n_j)}. \quad \text{(C.12)}$$

Given λ_2 and the estimates of (α_2, β_2) obtained by maximizing (C.10), we obtain estimates of (α_3, β_3) by maximizing the log-likelihood function given by

$$L_3^* = \sum_j \ln L_{3j}. \quad \text{(C.13)}$$

It should be noted that while search procedures such as NLP do not guarantee a global optimum, we obtained highly similar estimates using a wide variety of starting points in the search procedure, which lends confidence to the estimates.

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