"PRICE ELASTICITY DYNAMICS OVER THE ADOPTION LIFECYCLE: AN EMPIRICAL STUDY"

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PRICE ELASTICITY DYNAMICS AND NEW PRODUCT ADOPTION: AN EMPIRICAL STUDY

Abstract

The role of elasticities in strategic pricing over the product lifecycle has received much attention in the marketing literature. The focus on first purchase, trial, or new product adoption is based on the managerial importance of targeting marketing efforts toward nonadopters; previous adopters may have regular repeat purchase behavior or will be satisfied with having adopted the innovation one time, as might be the case for durable products. This research tests competing hypotheses concerning the time path of price elasticities over the product adoption lifecycle. Unlike previous empirical research, our study explores price elasticity dynamics in the context of new product diffusion. In order to control for primary demand effects, first purchase data collected for 19 durable goods are used to estimate 20 alternative diffusion specifications commonly suggested in the literature. Price elasticity dynamics are then incorporated into the best diffusion specifications as determined by tests of nested and nonnested alternatives. Competing specifications of price elasticity dynamics are then examined to test the prevailing hypothesis suggested in the literature: price elasticities increase over the adoption lifecycle. This procedure leads to a number of research propositions which may explain the divergence between the empirical results reported and the hypothesized dynamics.

INTRODUCTION

The role of elasticities in strategic pricing over the product lifecycle has received much attention in the marketing literature (see, for example, Hanssens, Parsons and Schultz 1990, Chapter 8; and Simon 1989, Chapters 5 and 6). The focus on first purchase, trial, or new product adoption is based on the managerial importance of targeting marketing efforts toward nonadopters; previous adopters may have regular repeat purchase behavior or will be satisfied with having adopted the innovation one time, as might be the case for durable products. With the exception of the brand-level model reported in Simon (1979), which does not explicitly consider the diffusion process, normative diffusion studies have assumed a constant price elasticity, elasticity being proportional to price, or a single direction time path over the product lifecycle (see Mahajan, Muller and Bass 1990 for a review of diffusion models used in normative and empirical pricing studies). Critical to such pricing decision are empirical studies, as reviewed by Lilien and Yoon (1988), Tellis (1988), and Simon (1979), which find that elasticities vary over the product lifecycle. Although these studies provide valuable evidence for brand level or industry level sales, there is little evidence showing whether elasticities vary over the "adoption" lifecycle or the diffusion process. Should it exist, such variation will clearly affect managerial efforts to price products optimally toward nonadopters.

The literature has recently noted the importance of understanding product class behaviour in formulating firm-level marketing strategies (see for example, Mason 1990). The research presented here empirically investigates price elasticity dynamics over the category adoption lifecycle. While previous theoretical discussions of price elasticity dynamics over the brand/product lifecycle have suggested that particular paths should be observed (for example Mickwitz 1959, and Parsons 1975), Robertson (1967) presents the first theoretical discussion of new product adoption and price sensitivity dynamics over the diffusion process. Extending the research of new product diffusion (Rogers 1983) into marketing, Robertson suggests that innovators or early adopters of most products have relatively high incomes and are therefore less sensitive to price changes than later adopters. The typical profile of innovators as having high incomes has been frequently observed in marketing (Robertson 1971) and general diffusion studies (e.g., Rogers, p. 252). Early adopters are less likely to be sensitive to price changes to the extent "that venturesomness is almost an obsession with innovators" (Rogers, p. 248).

The central hypothesis tested in this paper is founded in the theory that as the product innovation reaches more risk-averse segments of the population, elasticities increase (hereafter referred to in absolute value unless otherwise indicated):

H_0: New product adoption elasticities begin low and then increase as categories mature.

It should be noted that exceptions to this hypothesis may occur since the typical adopter category profile may not hold for some innovations. Care must be taken in investigating categories which, on an a priori basis, are likely to have been adopted by the typical innovator as profiled by Rogers and Robertson; in this research we study electronic consumer durables.

The "increasing elasticity" hypothesis has also found acceptance, though for different reasons, in the brand-level product-lifecycle literature. In contrast to Mickwitz who contents that elasticities should increase than decrease, or Parsons who contends that elasticities should decrease, Nagle (1987, pp. 152-153) contends that price sensitivity is lowest during early phases of the lifecycle and reaches its maximum level during maturity/decline phases. Tellis (1988) and Tellis and Fournell (1988) concur by arguing that few competitive substitutes exist during early stages of the product lifecycle and that consumers may be ill informed of competitive alternatives. Brand-level elasticities should begin low, then increase as categories mature and consumers become better informed. Though Simon (1979) finds that brand-level elasticities initially fall (for household cleansers and pharmaceuticals), elasticities ultimately increase. Confirming the hypothesized pattern, Liu and Hanssens (1981) find that elasticities increase over the product lifecycle for inexpensive gift items. In a meta-analysis of previous studies, Tellis (1988) reports that brand-level price elasticities also increase over the lifecycle. Again, while such works are valuable for understanding brand-level or category level sales elasticities (see Lilien and Yoon, 1988), they are not directly comparable to the research reported here given that our focus is on new product adoption at the category level.

General Approach

This research differs from previous empirical studies of elasticity dynamics by (1) considering elasticities of first purchases (or the adoption process) and explicitly modeling stages of the lifecycle via the diffusion process; and (2) investigating elasticities of consumer durables using multiple-decade time series data for each category, as opposed to a cross-section of categories assumed to be at different stages of the lifecycle. Previous studies have either investigated brand-level or industry-level sales (as opposed to adoption data) for frequently purchased consumer products, pharmaceuticals, and industrial products. With the exception of Liu and Hanssens (1981), one methodological issue in most of these studies is the identification of the lifecycle stage (e.g., introduction versus decline), since the data analyzed cover only one particular stage. The data used here cover multiple stages for each category studied. First, a diffusion process is modeled for each category so as to capture primary demand effects. Though not the primary focus of this paper, pairwise tests of twenty nested and nonnested nonlinear diffusion models generate a number of original conclusions with respect to parameterization requirements and the contribution of a number of diffusion specifications developed in the literature over the past three decades. Second, price elasticity dynamics are tested for prices adjusted and unadjusted for income changes via seven alternative (nested and nonnested) specifications and three functional forms (one separable and two non-separable). The examination of competing models provides tests for the existence of elasticity dynamics. Similar time varying parameter specifications have been used in marketing to test for elasticity dynamics (e.g. Wildt 1976). The next section of this paper details the research methodology, which is followed by the empirical results, a discussion of possible interpretations, and concluding remarks on managerial and research implications.

MODELING PROCEDURE

Diffusion Specifications

The modeling of the underlying diffusion process used in this study finds its roots in the model proposed by Bass (1969). Of the many new product diffusion models explored in marketing, as noted by Mahajan, Muller and Bass (1990) in their extensive review of the literature, the specification proposed by Bass (1969) has received widest acceptance. Generalizing models developed by Fourt and Woodlock (1960) and Mansfield (1961), the discrete-time econometric version of the Bass model postulates that first purchases (adoption) of a new durable product at time t ($f(t)$) are a function of cumulative first purchases ($F(t)$) up to but not including t and the total number of potential adopters M:

$$f(t) = \left(a_0 + b_0 \frac{F(t)}{M}\right)(M - F(t)) \tag{1}$$

where the estimated constants, a_0 and b_0 have been labeled the coefficients of innovation and imitation or of external and internal influence, respectively (see Mahajan and Muller 1979; Mahajan and Peterson 1985; Mahajan and Wind 1986; and Mahajan, Muller and Bass 1990 for reviews of Bass model extensions).

The Bass model has the desirable feature of assuming that the adoption of a new innovation by an individual is influenced by factors external to product experience, as captured in the coefficient of innovation, and factors based on interpersonal influences and cumulative learning, captured in the coefficient of imitation. Following diffusion theory, early adopters are less affected by peer adoption, whereas later adopters are mostly influenced by market experience (e.g., word-of-mouth or visual communication by innovators).

In order to capture more complex market phenomena, the Bass model has been modified to incorporate dynamic market potentials (Mahajan and Peterson 1978; Mahajan, Jain and Malhotra 1979), nonuniform interpersonal influences (Easingwood, Mahajan and Muller 1983), and heterogeneous adopter populations (Jeuland 1981; Chatterjee and Eliashberg 1989). The inclusion of these modifications is especially critical when studying long run diffusion processes (i.e., those spanning multiple decades in the case of consumer durables).

The Bass model has also been modified to incorporate price changes over the product lifecycle. Normative extensions include those by Robinson and Lakhani (1975), Bass (1980); Dolan and Jeuland (1982); Bass and Bultez (1982); Kalish (1983, 1985); Dockner and Jorgensen (1988); and Narasimhan (1989), among others. Empirical studies which incorporate price into the Bass model include, Bass (1980); Rao and Bass (1985); Kamakura and Balasubramanian (1988); Horsky (1990); and Jain and Rao (1990). These empirical studies demonstrate that price plays an important role in new product adoption when Bass-type diffusion processes are modeled. For the most part, elasticities are assumed constant or proportional to price over the time periods studied due to their limited duration. The simultaneous modeling of dynamic price elasticities, non-uniform influences, dynamic potentials and heterogeneous adopter populations has yet to be considered in the literature.

The approach taken here follows previous empirical studies by first establishing an underlying diffusion process for a given category and then incorporating price using one or more specifications. For example, Jain and Rao (1990) first develop a continuous-time formulation of the Bass model for the four product categories studied. Price is then incorporated using three alternative specifications. Since the research here considers a larger number of categories spanning longer periods of time, it is not apparent that the original specification of the Bass model, equation (1), or any single specification will adequately control for the underlying diffusion process. Assuming a dynamic adopter population, a supra-diffusion specification, equation (2), is therefore used as a starting point to model underlying diffusion patterns:

$$(2) \qquad f(t) = \left(a_i + b_i \left(\frac{F(t)}{c_i M(t)}\right)^{(1+d_i)}\right)\left(c_i M(t) - F(t)\right)^{(1+e_i)}$$

where a_i, b_i, c_i, d_i, e_i are constants for category i. Equation (2) belongs to a class of flexible diffusion models which allow for a variety of nonsymetric diffusion patterns (see

Mahajan, Muller and Bass 1990). Kamakura and Balasubramanian (1988) and Jain and Rao (1990) use the parameter c_i to adjust the market potential M(t), which is set exogenously as the number of households wired with electricity, for the nonadoption by certain households (see also Tigert and Fariva 1981; Mahajan and Peterson 1978; and Mahajan, Jain and Malhotra 1979 who set M(t) to be exogenous); c_i therefore measures the ultimate penetration level of households ($0 < c_i < 1$). Easingwood, Mahajan and Muller (1981) control for nonuniform interpersonal influence by incorporating the constant parameter d_i ($-1 < d_i < \alpha$). Jeuland (1981) controls for heterogeneous adopter populations (tastes, income, and so forth) via the parameter e_i ($0 < e_i$). For each category examined, nineteen models nested within equation (2) can be considered (see Table 1 for alternative model specifications). In reference to Table 1, the following models have previously been examined in the literature (while modifying for dynamic market potentials):

Models	Authors
20	Fourt and Woodlock (1960)
19	Mansfield (1961)
17	Bass (1969)
15	Easingwood, Mahajan and Muller (1981)
9	Easingwood, Mahajan and Muller (1983)
11	Jeuland (1981)
12, 14, 18	Kamakura and Balasubramanian (1988)

In addition to these previously investigated models, a number of hybrid models are specified. For example, Model 7 in Table 1 assumes that nonuniform interpersonal influence is present, that the market potential is all households wired with electricity (which varies over time), that external influences are not present, and that the diffusion process is over a heterogeneous adopter population (a hybrid of Mansfield, Easingwood et al., Mahajan and Peterson, and Jeuland specifications).

The appropriate specification for a given category is largely an empirical issue. For some categories, diffusion may have occurred in a symmetric fashion which may reflect uniform interpersonal influences. In such cases, d_i will not be required in the underlying diffusion specification (for the category concerned). The purpose of exploring alternative diffusion models is not to determine the best diffusion model for consumer durables in general, but to control for the underlying diffusion process using the appropriate specification for each category individually. As Tellis (1988, p. 336) notes, models using time series as a dependent measure can create problems in correctly estimating price elasticity dynamics:

(1) "Sales are typically low in the introductory stage and high in maturity. So price elasticity, estimated ... with sales as the dependent variable, would be more negative in the earlier stages of the lifecycle"; and

(2) "... if response is measured as sales and if primary effects are strong as in the early stages of the lifecycle, the price elasticity would be more negative; conversely if primary demand effects are weak as in maturity, the sales measure should lead to a less negative elasticity."

Although these cautions are made with respect to brand-level product lifecycles, they are nonetheless applicable to category-level first purchases, which generally have high primary demand effects early in the lifecycle. The approach taken here to avoid such problems is to impose an underlying diffusion process to account for primary demand effects, thus "deseasonalizing" the category for the stages of the product lifecycle. The application of the resulting models to a large number of categories with widely varying price and sales paths can also compensate for the typical nature of product lifecycle curves. Procedures used to estimate and compare competing specifications are addressed later in this paper.

Incorporating Price

Assuming that the underlying diffusion process has been identified, price can be incorporated as a separable function of the diffusion process, as a nonseparable function of the diffusion process, or as affecting the market potential (Kalish 1983; Dockner and Jørgensen 1988). Only the former two cases are considered here, as Kamakura and Balasubramanian (1988) and Jain and Rao (1990) find that price generally affects the rate of diffusion (coefficients a_0 and b_0) and not the market potential for consumer durables.[1] If $q_{i(.)}$ is defined as the underlying diffusion process for category i, then price can be incorporated in a separable manner as follows:

(3) $$f(t) = q_{i(.)}\, P(t)^{g(A(t))}$$

[1] Unreported analyses of the data used in this study yield similar conclusions.

where $P(t)$ is the price in period t and $g(A(t))$ is a price elasticity function dependent on the age of the product category $A(t)$.[2] For any moment in time, elasticities are assumed constant; the diffusion process shifts the demand function over time which can pivot based on values of g (A(t)). This multiplicative formulation is closely associated with those of Robinson and Lakhani (1975), Bass (1980), Dolan and Jeuland (1981), and Bass and Bultez (1983), which are generalized by Kalish (1983). It is hypothesized that $g(A(t))$ is negative and that $\frac{\partial\, g(A(t))}{\partial\,(A(t))}$ is negative over the values of A(t), as discussed in the previous section.

Nonseparable versions of equation (3) would multiply either the coefficient of innovation or of imitation by the price term $P(t)^{g(A(t))}$. For example, two plausible nonseparable specifications include:

$$(4) \qquad f(t) = \left(a_0\, P(t)^{g(A(t))} + b_0 \frac{F(t)}{M(t)}\right)(M(t) - F(t))$$

$$(5) \qquad f(t) = \left(a_0 + b_0\, P(t)^{g(A(t))} \frac{F(t)}{M(t)}\right)(M(t) - F(t))$$

In equation (4), price is assumed to affect only external influences or the propensity of households to adopt an innovation independent of internal/interpersonal influences. One can imagine this type of effect when a large portion of opinion leaders (which may represent a large portion of potential adopters) adopt as a function of price. In contrast, equation (5) may illustrate situations when opinion leaders or innovators do not adopt as a function of price. However, price changes may enhance information seeking/transmitting behavior and affect one's propensity to imitate; a dramatic change in price, for example, may prompt conversations between adopters and nonadopters. Given the lack of theoretical basis for selecting one specification over another, the appropriate integration of price is best determined on an empirical basis and is likely to be a function of each category's characteristics.

Finally, a time-varying parameter formulation of $g(A(t))$, the dynamic elasticity function, is proposed in equation (6):

$$(6) \qquad g(A(t)) = h_i + j_i\, A(t) + k_i\, A(t)^2$$

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[2] An alternative specification would allow the elasticity to be a function of product category penetration g(F(t)/M(t)). As a measure of "maturity" this formulation suffers from having little or no variation for years after the category penetration reaches a plateau. The results reported in this paper are not sensitive to the two alternatives with the exception of "plateau" years. Nonlinear transformations of A(t) are not tractable given that $1 > F(t)/M(t) > 0$. The use of A(t) also reduces the risk of multicollinearity.

where h_i, j_i and k_i are constants associated with category i. An important advantage of this form over alternatives is its flexibility in fitting the various alternative hypotheses (Shoemaker 1986). There are six specifications nested in equation (6):

(7) $g(A_{(t)}) = h_i + j_i A_{(t)}$

(8) $g(A_{(t)}) = h_i + k_i A_{(t)}^2$

(9) $g(A_{(t)}) = h_i$

(10) $g(A_{(t)}) = j_i A_{(t)} + k_i A_{(t)}^2$

(11) $g(A_{(t)}) = j_i A_{(t)}$

(12) $g(A_{(t)}) = k_i A_{(t)}^2$

Across all specifications, we would generally expect $g(A_{(t)})$ to be negative over the values of $A_{(t)}$. The advantage of exploring the nested alternatives, as opposed to the quadratic formulation in equation (6), is the ability to reduce risks of multicollinearity affecting parameter estimates. More than one nested alternative may, however, lead to similar time paths for elasticities. For example, equations (6), (7), (8), (10), (11), and (12) can all indicate that price elasticities begin low, in absolute value and then increase, depending on the values of estimated parameters. The rate of increase and magnitude will vary from one specification to another, though the direction may be identical. Since this research is concerned with direction, as opposed to the absolute magnitude and acceleration of elasticity changes, the inclusion of nested alternatives can be seen as an internal test of validity. If two specifications are statistically equivalent (e.g., in terms of a likelihood ratio test or another test), yet yield contradictory conclusions with respect to the direction of elasticity changes, then no hypothesis is supported.

EMPIRICAL PROCEDURE

Data

In order to focus on elasticity dynamics over the adoption lifecycle within the context of new product diffusion, the underlying data used to test the hypothesis need to span multiple decades so as to insure that the cycle is well represented (introduction, growth, peak, and decline in adoption levels). Over seventy categories of consumer durables were screened for the existence of data on first purchase (adoption) and price. Of these categories, only nineteen met the criteria of including multiple lifecycle stages while offering enough observations to estimate the alternative specifications. Most empirical diffusion studies of consumer durables report fewer categories than this, as the focus is on model illustration and not on testing research hypotheses. In our case, the nineteen categories are a convenience sample based on the availability of secondary data sources.[3]

In order to estimate the specified diffusion and dynamic elasticity functions, the following data were collected for each category studied: average unit prices calculated using unit sales and retail value; number of households wired for electricity (M(t)); and number of wired households having adopted at least one unit of the product category (f(t) and F(t)).[4] Prices are operationalized using two different definitions: (1) adjusted for changes in cost of living P(t), and (2) adjusted for both cost of living and average household income $\bar{P}(t)$.[5] The first definition of price is similar to those used by Jain and Rao (1990), Kamakura and Balasubramanian (1988), and Bass (1980). In the latter case, prices represent average budget shares of the durables over lifecycles, which may be subject to the effects of substantial income changes possibly generated by business cycles.

Table 2 summarizes the categories included in this study. The categories and years reported are based on the availability of continuous annual cross-sectional surveys of wired household penetration and include first adoption of households based on the purchase of either new or used durables. Although sales and price statistics are available early in a category's history, penetration surveys for some categories often begin a few years after the categories were established (especially for steam irons, vacuum cleaners, and washers). The lag in penetration reporting, while reducing degrees of freedom, may affect the impact of early adopters (innovators) and the effects of high income purchases on price elasticities. Figure 1 indicates, however, that the introductory phase of most categories is well represented in the series. With the exception of Kamakura and Balasubramanian (1988), previous diffusion studies of consumer durables have relied on early sales data, as opposed to first purchase/adoption data. As indicated in Table 2, the fundamental differences in the two series can be seen by the timing of first purchases whose first or ultimate peak can precede or follow the sales peak by several years or several decades. Given the nature of the hypotheses and the diffusion model specifications, first adoption data are more appropriate for this study.

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[3] Data sources include various issues of Merchandising, Merchandising Weekly, Electronics Weekly, Dealerscope, Dealerscope Merchandising, and Appliance. Certain data for televisions were supplied by the Electronics Industry Association and A.C. Nielsen.

[4] For the war years of 1942 to 1946, data were generally incomplete or not available; these years were omitted from the series reported.

[5] Prices are deflated by the consumer price index published by the U.S. Bureau of Labor Statistics and divided by average income, estimated by gross national product divided by total households; alternative series for these adjustments were not available on a continuous basis beginning in the 1920s. Prices are standardized about their mean values over the series in order to avoid scaling effects in the diffusion parameters; similar adjustments are made in Kamakura and Balasubramanian (1988), Bass (1980), and Jain and Rao (1990).

With respect to the concerns raised by Tellis, in only a few cases do the declines in prices not follow the typical learning curve decay function. Ranges, ironers, vacuum cleaners and electric washers, shown in Figure 1, have non-uniform diffusion and pricing patterns. This irregularity helps to alleviate the problems in time series analysis noted by Tellis. For product categories having more predictable price declines, first purchase curves (f(t)) often do not fit the typical diffusion pattern. For a number of categories, rapid first purchase growth occurs only after an extended period of time: 11 years for bed covers, 18 years for blenders, 18 years for clothes dryers, 14 years for dishwashers, 20 years for disposers, 18 or 36 years for ranges (due to a bi-modal diffusion), 21 years for freezers, 6 years for ironers, and 17 years for washers. For two categories, vacuum cleaners and steam irons, the first purchase diffusion pattern is highly irregular, while for black-and-white televisions the first purchase diffusion pattern consists of an initial spike and a low right-end tail. Srinivasan and Mason (1986) and Heeler and Hustad (1980) note that the Bass model is best estimated with a minimum of ten years input data (for forecasting and market potential estimation). For a number of the categories studied here the first purchase data show, over the first ten-year period, either minimal variation, an initial first purchase peak (among multiple peaks which are often of greater magnitude several decades later), or an ultimate peak/spike. One can therefore speculate that the initial, intermediary, or ultimate peaks may be more a function of price changes and dynamic elasticities than of an underlying diffusion process itself, depending on the category being studied. When interpreting parameter estimates care must be taken to refer to the underlying data presented in Figure 1 because of the cautions cited from Tellis and because of each category's individual diffusion characteristics. Finally, it should be noted that the length of certain series exceeds thirty years. It can be argued that technology-driven quality changes are not constant over these long periods; prices, adjusted for quality, are likely to have fallen more sharply than the data would indicate.[6] Also, the impact of secondary markets on average adoption price cannot be taken into account; again, actual prices paid will probably be lower, but highly correlated with those used in this study.

[6]. The lack of other marketing mix variables may also be problematic, though the consideration of elasticity dynamics across several categories within the same general industry (electronic durables) minimizes possible biases.

Estimation and Selection Procedure

Given the inherent nonlinearity in most of the diffusion models shown in Table 1, nonlinear least squares (NLS) is used to estimate each specification.[7] One advantage of NLS is that standard errors can be estimated for individual coefficients (Srinivasan and Mason 1986). However, the lack of continuous time formulations for each of the twenty alternative diffusion models introduces a possible time interval bias, since discrete time series data are used (Schmittlein and Mahajan 1982). Because there is little reason to believe that any bias will systematically vary from one category to another, and since the goal here is not to forecast the adoption of a particular product but to compare price elasticities across products, the results reported should be insensitive to such biases (Mahajan, Muller and Bass 1990). Mahajan, Muller and Bass (p. 9) note that parameter estimates do not differ greatly across estimation methods which control or do not control for such biases.

In order to compare alternative specifications, a six stage procedure shown in Figure 2 is followed. The first three stages focus on specifying the appropriate underlying diffusion process. Stage 1 involves estimating the twenty alternative diffusion models for each of the nineteen categories (380 runs). Stage 2 involves performing likelihood ratio tests for nonlinear nested models (see Judge et al. 1980, p. 758). Table 1 indicates which models are within the same family of nested alternatives. All models are, of course, nested within Model 1. For example, Model 20 is nested in Models 13, 14 and 17 which are nested in Models (6, 7), (6, 8), and (9, 11, 12), respectively, which in turn are nested versions of less parsimonious specifications. For a constrained model to be eliminated, the χ^2 distributed likelihood ratio test statistic is required to indicate a significant difference, at the $\alpha = .05$ level, between the full and constrained models. When there is no significant difference between nested alternatives, the constrained model is retained. This procedure is used in Kamakura and Balasubramanian (1988) for nested diffusion models. For each category, 41 nested likelihood ratio tests were performed (779 tests in total). This process of elimination may result in (1) a single retained model (e.g., Model 1), or (2) several nonnested models, usually having the same number of parameters, which remain in competition.

Stage 3 involves comparing the remaining nonnested alternatives. The test proposed by Cox (1961, 1962), modified to consider nonlinear specifications by Pesaran and Deaton (1978), is used to evaluate pairwise comparisons of remaining specifications. Using the same criteria as with the nested tests (e.g. $\alpha = .05$ significance level), models are

[7] For all estimated models an additive error term is used; multiplicative error specifications do not generally provide better fits to the data (see also Srinivasan and Mason 1986, p. 170, footnote 3).

eliminated in favor of parsimonious alternative specifications based on the χ^2 distributed test statistics. As noted by Judge et al. (1985), the Cox test is not symmetric and may yield inconclusive results, in which case both models are retained. In practice, virtually all nonnested tests are performed across models with an equal number of parameters. For a given category, this procedure may result in one or more retained models.

Once one or more appropriate diffusion models are retained, Stage 4 integrates price in either separable or nonseparable forms or both. Estimates using the seven alternative specifications for g(A(t)) given in equations (6) to (12) are obtained using both definitions of price, P(t) and $\overline{P}(t)$. Stage 5 involves tests of nested alternative specifications of the dynamic price elasticity function (likelihood ratio tests for each retained diffusion model for each category). Cox tests of remaining nonnested models are performed in Stage 6. Unlike tests of alternative diffusion specifications, where parsimony is desirable in order to avoid potential multicollinearity problems (though the behavior of the diffusion parameters themselves is not our primary focus), if two nonnested elasticity specifications differ in degrees of freedom, yet are not statistically different in fit, both are retained and reported. The parameter values of the retained models are used to test the research hypothesis. The plausibility of parameter values or some other nonstatistical criteria can be used to evaluate retained models which yield conflicting conclusions, otherwise the test for elasticity dynamics may be inconclusive.

The six stages can be considered as a two-step methodology: (1) diffusion specification, and (2) price incorporation. As with all step-wise procedures, specification errors may occur if a parameter is dropped in Step 1 which could be significant in Step 2. The methodology proposed assumes that if a parameter is dropped in Step 1 due to a likelihood ratio test (for example, a_i, the coefficient of external influence), then the incorporation of price will not change this lack of significance. In such a case, price does not influence one part of the diffusion process (external influences). Because a diffusion structure is retained, in all cases, price can affect or even dominate the diffusion process. Specification error biases in this regard are minimized. When the supra-diffusion model (Model 1) is retained, all critical pairwise tests are performed for all price specifications and functional forms; specification error bias of the type discussed above will not be present. Pairwise tests of all potential specifications (nested or nonnested) leads to an unmanageable number of comparisons (e.g. several million).[8]

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[8] Based on the following calculation: 20 diffusion models x 7 price specifications x 3 functional forms = 420 models; pairwise tests among 420 models = 175,980 tests; 175,980 tests x 19 categories = 3.3 million tests.

EMPIRICAL RESULTS

Diffusion Specifications

The number of categories studied prevents a complete reporting of all parameter estimates and tests.[9] Rather, Table 3 summarizes the retained diffusion models after Stages 1, 2 and 3 are performed. The sum-of-squared errors (SSE) and the simple correlation (r) between actual and fitted observations are reported, as is commonly suggested for nonlinear models (Judge and al., 1985). For comparative purposes, Table 3 shows the SSE and r for the original Bass model specification which performs relatively well for many of the categories. Though not reported, the coefficient of innovation a_i is not consistently significant across the categories using the Bass specification (Model 17); this insignificance may result from the reporting lag of adoption data discussed earlier. A number of conclusions can be drawn from Table 3 with respect to the diffusion model specifications:

- No single specification is dominant in modeling the diffusion process for the nineteen consumer durables studied.

- The market potentials of seventeen categories (89 percent) require adjustment. Estimates of c_i are generally correlated with penetration levels reported in Table 1. Values greater than one for c_i can be explained, in part, by likely changes in category definition and the survey methodology used over time (Kamakura and Balasubramanian 1988).

- All but three categories (84 percent) exhibit nonuniform interpersonal influences as captured in significant values of d_i; the estimates of d_i vary within a reasonable range ($-1<d_i<\infty$), as discussed by Easingwood, Mahajan and Muller (1983).

- Six of nineteen categories (32 percent) require adjustment for heterogeneous adopter populations, as discussed by Jeuland (1981).

- The level of parameterization required to model the diffusion process varies from one category to another: 5 percent of cases require only one parameter; 11 percent require two parameters; 32 percent require three parameters; 37 percent require four parameters; and 16 percent require five parameters.

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[9] Though voluminous, these are available on request.

- One category (5 percent of the total) is a hybrid specification of the Fourt and Woodlock model which exhibits only innovative/external influences, a_i; the remaining categories exhibit either pure imitation/internal influences, b_i, as originally modeled by Mansfield mixed influences as specified in the Bass model or both (Mansfield or Bass-type diffusion processes); three categories (16 percent) are best modeled using the five-parameter supra-diffusion model, equation (2), Model 1.

- A majority of categories are best fit by hybrid diffusion specifications not as yet explicitly investigated in the normative or empirical diffusion literature.

The retained specifications reported in Table 3 confirm the importance of the mixed-influence Bass model as a basis for controlling for the underlying diffusion process. Table 3 also confirms the contribution of efforts to modify the Bass model for more complex market behavior and diffusion patterns. It should be understood that estimates of a_0 and b_0 in equation (1) are not analytically comparable with a_i and b_i in Table 4. The introduction of the flexible diffusion parameters d_i and e_i redefine internal and external influence parameters as originally modeled by Bass in equation (1).[10] Low estimated values (at low significance levels) of a_i and b_i are due in part to the incorporation of flexible diffusion parameters.[11] These low values do not therefore imply that internal and external influences are absent. Heeler and Hustad (1980) and Schmittlein and Mahajan (1982) note that multicollinearity present in mixed influence models often leads to unstable estimates of diffusion parameters with large standard errors. For the categories studied here, however, the elimination of either a_i or b_i, for the retained models having both coefficients, substantially reduces the fit of the models as born out by likelihood ratio tests. Although the reported estimates of a_i and b_i may make developing normative statements and subsequent meta-analyses difficult, Figure 1 illustrates that the retained models fit the underlying data well and will fulfill their purpose in controlling for the diffusion process before price is integrated; $\hat{f}(t)$ and $f(t)$ signify fitted and actual adoptions, respectively, in Figure 1.

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[10] Comparing equation (1) with equation (2), the supra-diffusion model, one finds:
$a_0 = a_i \left(c_i M(t) - F(t)\right)^{e_i}$, and
$b_0 = b_i \left(c_i M(t) - F(t)\right)^{e_i} \left(F(t)/(c_i M(t))\right)^{d_i}$

[11] In particular, the elimination of e_i from the retained specifications generally yields statistically significant estimates, which vary between 0 and 1, of a_i and b_i in those specifications where e_i is retained. When e_i is retained and estimated to be positive, a_i and b_i are estimated to have small (insignificant) estimated values. In two cases (calculators and built-in ranges), e_i was estimated to be negative in the retained model. The next best models are used given their greater plausibility; the results reported on elasticities are insensitive to these exceptions.

Price Elasticities

Tables 4 and 5 report those categories for which Stages 4 to 6 yield significant estimates for one or more of the alternative specifications for g(A(t))when prices are unadjusted, P(t), and adjusted, $\overline{P}(t)$, for real income changes, respectively. Figure 3 shows the fitted $(\hat{f}(t))$ and the actual (f(t)) adoption data for those categories which were affected by price (the retained models with the lowest sum-of-squared errors). As expected, g(A(t)) is generally estimated to be negative in value, though may have positive values over a portion of the lifecycle for some categories; elasticity estimates generally fall within the range of previous studies (see Tellis 1988).[12] The incorporation of the dynamic elasticity function $P(t)^{g(A(t))}$ or $\overline{P}(t)^{g(A(t))}$ into the retained diffusion models from Table 3 allows us to consider three research questions: (1) Do price elasticities increase over the adoption lifecycle as hypothesized? If not, are price elasticity dynamics similar across categories? (2) Are price elasticity dynamics sensitive to the two alternative definitions of price (adjusted, $\overline{P}(t)$, or unadjusted, P(t), for real income changes)? (3) Do separable functional forms better capture the diffusion process than nonseparable forms for a given category or in general?

Table 6 addresses the first two questions. Each category is classified as yielding weak or strong support for a particular pattern of price elasticity dynamics. Weak support for price elasticities being constant signifies that elasticities were found to be not statistically different from zero over the entire lifecycle (constant, yet not significant elasticities). Weak support for the remaining patterns implies that a competing specification with constant elasticities was also retained based on Cox or likelihood ratio tests (e.g. for refrigerators based on the income-adjusted price definition). Categories in parentheses are those whose price is unadjusted for income, [P(t)], and which are not categorized in the same cell as when prices are adjusted for income, $[\overline{P}(t)]$. From Table 6, we can draw the following conclusions:

- There is no consistent pattern of price elasticity dynamics over the adoption lifecycle for the durables studied; the "increasing elasticity" hypothesis is not consistently supported.

- For some low- and high-priced categories, price does not play a major role in the adoption process based on the weak test of constant elasticities; Jain and

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[12] Strictly speaking, estimates from nonseparable functional forms measure price sensitivity dynamics, as opposed to price elasticity dynamics; this does not detract from the study's conclusions. Positive elasticities over a portion of the lifecycle do not imply that elasticities are statistically greater than zero, for a given year, as statistical significance is based on independent tests of each elasticity parameter over the time series.

Rao (1990) and Kamakura and Balasubramanian (1988) report such results for only low-priced categories.

- Unlike findings from previous empirical studies, price is found to play a role in the diffusion of some low-priced durables (e.g., calculators, electric bed covers, and water pulsators).

- Estimated price elasticity dynamics can be sensitive to the two alternative price definitions though they are not generally; the diffusion process is in general better modeled with income and inflation adjusted prices, $\overline{P}(t)$, as opposed to inflation-only adjusted prices, $P(t)$.

For some definitions of price, some categories yield inconclusive results. For ironers $[\overline{P}(t)]$ and disposers [P(t)] the retained models yield conflicting patterns. In the case of freezers [P(t)], retained specifications yield increasing elasticities toward the end of the lifecycle (consistent with the other definitions of price, $[\overline{P}(t)]$, but either increasing or decreasing elasticities in the early stages).

With respect to the final question on functional forms, for those categories which have both external and internal influences and significant elasticity estimates, both separable and nonseparable forms are retained in Tables 5 and 6 without one form being dominant. Within one category (room air conditioners) the separable and two nonseparable forms are retained in Table 5. For ironers, bed covers, and built-in ranges, two alternative forms are retained. For some categories (e.g., vacuum cleaners, $\overline{P}(t)$) there are clear winners (the nonseparable external influence functional form). The appropriate functional form appears to be either category specific or not critical in terms of estimating the impact of price changes on the adoption process. Though not considering elasticity dynamics, Kamakura and Balasubramanian (1988) similarly find, based on a study of six categories, that prices can be best modeled as affecting either internal influences or both internal and external influences, depending on the category.

Interpretation

Table 6 demonstrates that the prevailing hypothesis (increasing elasticities) is not clearly supported. Rather, category specific factors appear to regulate elasticities dynamics. In particular, one can separate categories into five classifications:

(1) "necessities" or categories having reached penetration levels exceeding 90 percent: calculators (97.2 percent), refrigerators (99.9 percent), televisions: B & W (99.9 percent), televisions:

color (90.5 percent), steam irons (99.8 percent), vacuums (99.9 percent), washers (95.7 percent);

(2) "necessities" facing penetration decline (or de-adoption): television: B & W, vacuum cleaners, washers;

(3) Other categories facing declining penetration: freezers, ironers, disposers, room air-conditioners;

(4) "Would be" necessities or those which have not yet reached 90 percent penetration but have not yet reached a plateau: bed covering (64.2 percent), blenders (52.4 percent), microwave ovens (59.4 percent), dishwashers (43.0 percent);

(5) Categories having reached a stable penetration plateau (not necessities, not declining): built-in ranges (19.6 percent), clothes dryers (61.5 percent), water pulsators (14.6 percent).

The classification of some categories as necessities is consistent with the body of research on consumer acquisition priorities for home appliances which finds that such durables are ranked highly among households' priorities (see, for example, Dickson, Lusch and Wilkies 1983; Clarke and Soutar 1982; Kasulis, Lush and Stafford 1979; and Hauser and Urban 1986). Categories classified as facing decline have reached their ultimate penetration levels and have since declined.[13] However, only observations up to but not including the decline are included in this study. Of these, only ironers (clothes presses) have virtually disappeared as a household durable; penetration surveys were no longer conducted for this category as of the late 1950s. The remaining categories have declined in penetration yet show no signs of extinction. Such a classification allows us to consider alternative propositions in order to explain elasticity dynamics and, in particular, consider economic effects commonly associated with brand-level lifecycles (e.g. competitive substitution).

The formation of price elasticities (static) and the effect of price changes on purchasing behavior are commonly understood in the economies literature to be functions of three broad factors:

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[13] Black-and-white televisions face greater competition from color televisions (penetration falling from 99.9 percent in 1973 to 56.7 percent in 1987); stand-alone freezer penetration has declined from 44.9 percent in 1978 to 40.7 percent in 1987, due in part to the extension of freezer compartments in refrigerators. Ironers face competition from steam iron, and dry cleaning/pressing services. Disposers reached 50 percent penetration in 1983 before falling to 46 percent penetration in 1987. Floor vacuum cleaner penetration reached 99.9 percent in 1976 and fell to 92 percent in 1984 due, perhaps, to changes in lifestyle and the introduction of hand portable vacuum cleaners. Electric washers face greater competition from coin laundry mats which have grown with changes in housing trends (95.7 percent penetration in 1961 falling to 81 percent penetration in 1965). Room air conditioners reached 55.5 percent penetration in 1979 before falling to 26.8 percent in 1987 due to the use of central air systems and heat pumps.

(1) the existence of direct substitutes

(2) the proportion of total income spent on the product in question (indirect substitution)

(3) the degree to which a product falls within the opportunity set of consumers; or, as managerial texts often state, the degree to which a product is considered a necessity (Pappas and Brigham, 1979, p. 141).

The first two factors find their origins in the early works of Slutsky (1915), whose famous equation, and numerous variations decompose the total response of price changes into substitution and income effects. For example, price changes will not only affect the relative trade-off between competitive products but may also affect the entire choice set available to the consumer, who is now able to purchase more (or less) of the product in question or other products than previously possible. The direct substitution effect results in a positive correlation between the number of close substitutes and price elasticities. The second component, the income effect, is likely to be small for those products which represent an insignificant amount of household budgets. However, the income effect is dependent on the third factor, the degree to which a product falls within the consumption set of households or is considered a "necessity". If a product is so unnecessary that it falls outside of a household's typical consumption set (e.g. a Rolls Royce), then even large changes in price will generate little or no income or indirect substitution effect (Silberberg 1978, p. 245). Ceteris paribus (e.g., for a given opportunity set), sales of higher priced products which account for a significant portion of household budgets will have greater sensitivity to price changes than inexpensive products with low budget shares. Likewise, the more necessary the product the lower the price elasticity in absolute value.

The variety of categories studied here allows us to consider the three factors and their impact on price elasticity dynamics:

- For the seven categories facing economic obsolescence or competitive substitution, price elasticities generally show increases toward the end of the lifecycle (freezers, disposers, room air conditioners, floor vacuums), with the exception of black and white television, electric washers (which can be classified as necessities), and ironers.

- Of the categories which can be classified as necessities (having penetrations in excess of 90 percent), most exhibit declining elasticities toward the later stages of the lifecycle (black and white television, calculators, refrigerators), or static elasticities not statistically different from zero (color television, steam irons [P(t)], and washers), which is consistent with the consumer acquisition priorities literature.

- Of the categories susceptible to being classified as necessities which have increasing penetration, elasticities are either constant (bed covers) or not statistically different from zero (blenders, dishwashers, microwave ovens).

- For categories which have reached a plateau of penetration and which do not appear likely to reach a penetration exceeding 90 percent (ie., which are not absolute necessities), elasticities increase throughout the lifecycle, or toward the later stages (built-in ranges, electric clothes dryers, and water pulsators).

Though limited to nineteen categories (an exploratory sample), these empirical conclusions would tend to support a number of theoretically plausible research propositions.

The first economic factor states that the number of close substitutes is positively correlated with price elasticities (in absolute value). At the brand level, Tellis (1988) and Tellis and Fornell (1988) note that few products may compete during the early stages of the product lifecycle or consumers may be ill informed of competitive alternatives. Brand-level elasticities should begin low, then increase as categories mature and consumers become better informed. When considering category-level adoption, new categories may face few substitutes, if any. This condition may continue for several years or several decades until economic or technological obsolescence occurs. Anticipating or understanding how obsolescence can affect sales is a critical aspect of strategic planning (Levinthal and Purohit 1989). This form of competition (direct substitution) leads to the following proposition:

P1A: As product categories face increased competition via direct substitutes or obsolescence, price elasticities will increase over the adoption lifecycle.

There is a plausible alternative proposition to P1A:

P1B: Product categories which dislodge existing behavior will exhibit high initial elasticities; as the category becomes accepted as the dominant behavior, these elasticities will decline.

Diffusion theory and empirical observations indicate that most innovations replace some existing technology or behavior (Rogers 1983; Norton and Bass 1987). When first introduced in the early 1900s, refrigerators faced competition from ice boxes or cellars which received periodic deliveries of ice blocks. The decision to install an electric refrigerator once involved considering the two alternative technologies. This decision was more complex than it is today given that, in its earliest years, refrigerator installation often involved contractors sending multiple crews to a home to cut away existing floor boards, pour cement to reinforce metal frames, bolt condensers to the new floor, and independently build the refrigeration compartment. Today, most people do not consider ice boxes or cellars as substitutes for refrigerators. Combining hypotheses P1A and P1B, the effect of direct product substitution can evolve over the adoption lifecycle such that:

P1C: Elasticities are high as a category replaces existing technologies, then decline as the category becomes the dominant (only) alternative, and rise when obsolescence or competitive substitution increases.

The general proposition is not therefore whether substitutes affect elasticities, but whether the degree of substitution varies systematically over the category-level adoption lifecycle which will in turn lead to dynamic elasticities.

As stated earlier, the second factor, income, has been considered by Robertson (1967) who extends the study of new product diffusion into marketing. Robertson suggests that innovators or early adopters of new products have relatively high incomes and are therefore less sensitive to price changes than later adopters.

P2A: Elasticities increase over the product lifecycle as lower income households adopt an innovation.

Two possibilities can generate alternative hypotheses to P2A. The first is the violation of the assumption that early adopters have high incomes. Exceptions may exist for products whose price is a relatively unimportant attribute (e.g., as might be the case for medical procedures or certain ethical drugs). Likewise, relatively inexpensive innovations which are sold through mass channels may not be purchased first by high income households. Secondly, the share of income that a durable represents may dramatically change over the product lifecycle due to a combination of real income increases and real price reductions. For example, in 1925 refrigerators represented 11.2 percent of average household income. This percentage had fallen to about 1.4 percent by 1979. Based on the income or indirect substitution effect discussed above, one can propose that:

P2B: Elasticities are highest in the early stages of the product adoption lifecycle when prices expressed as budget shares are highest; elasticities are lower thereafter.

As mentioned earlier, this alternative income proposition is itself affected by the extent to which an innovation is considered a necessity (within consumers' consumption sets). Adoption of "refrigeration," for example, does not necessarily imply adoption of "refrigerators" at all stages of the lifecycle; hence, refrigerators may be considered beyond the typical consumption set, especially during the introductory stage of the lifecycle. The more the innovation is perceived as a necessity, the more likely it will be considered within this set; the dynamics of this perception can depend on the diffusion process.

Research on diffusion by Rogers (1983), among others, finds that early adopters, who are less risk averse than later adopters, serve as opinion leaders to later adopters of an innovation. Rogers (p. 67) describes this process as a "collective-learning system in which the experiences of the earlier adopters of an innovation, transmitted through interpersonal networks, determine the rate of adoption of their followers." In particular, Rogers notes that learning reduces the perceived risk (e.g., financial) of adoption for nonadopters, implying that sensitivity to price will decline over the adoption lifecycle (all other factors held constant). Rogers (pp. 166-167) also notes that the diffusion of an innovation can create basic needs. As a category evolves from consisting in a monopolist's product (centralized diffusion), to one which is supplied by a larger number of firms (decentralized diffusion), basic needs will be better met and adoption will be more widespread (Rogers, p. 333; Gatignon and Robertson 1985, 1986). In the case of successful innovations, the necessity of a given innovation is likely to increase over the adoption lifecycle, implying the following proposition:

P3A: As a category matures and is perceived as a necessity by wider portions of the population, price elasticities will decline over the adoption lifecycle.

Rogers contends that the opposite may hold if an innovation becomes marginalized after learning reveals a lack of need. What may first be seen as a necessity may, over time, be seen as nothing more than a passing fancy:

P3B: Elasticities will decline over the adoption cycle but may eventually increase if an innovation is perceived as less necessary (all other factors held constant).

To summarize, the integration of economic and diffusion theories can yield a number of plausible elasticity time paths over the adoption lifecycle: increasing (P1A), decreasing

(P1B), decreasing then increasing (P1C), increasing (P2A), decreasing (P2B), decreasing (P3A), decreasing then increasing (P3B). The integration of these independent propositions may lead to a variety of time paths. While the elasticity dynamics observed in this study generally support these propositions, research which can better isolate and control for the factors discussed above will advance our ability to make better assumptions in subsequent normative analyses.

DISCUSSION

This research investigates price elasticity dynamics over the adoption lifecycle. In order to test the prevailing research hypothesis, a systematic six-stage methodology first generates appropriate diffusion specifications for each of nineteen durable goods categories. The retained models are used to control for the underlying diffusion process. Then two operational definitions of price are incorporated into the diffusion specifications using separable and nonseparable functional forms. Estimates of elasticity dynamics are obtained via nested and nonnested tests of seven alternative specifications of a general price elasticity function. This approach generates original contributions to marketing by (1) expanding upon previous efforts to model diffusion processes empirically while integrating more complex functional forms, and (2) estimating the effect of price on new product diffusion while testing alternative hypotheses concerning elasticity dynamics over the adoption lifecycle.

A number of authors have called for more empirical tests of new product models which integrate complex diffusion phenomena or marketing mix variables (Gatignon and Robertson 1986; Rao 1984; Easingwood, Mahajan and Muller 1983; Mahajan, Muller and Bass 1990; Kamakura and Balasubramanian 1988). The goal of this research is not to determine the best diffusion model across all categories but to estimate the most appropriate model for each of the nineteen durable goods categories individually. The comparison of twenty alternative diffusion specifications indicates that the Bass model and its recent modifications form a sound basis for modeling diffusion processes. However, there is no single model or level of parameterization that best fits the data across the categories studied, a finding consistent with Lavarajan and Gore (1990), who compare three alternative diffusion specifications across six innovations.

Though limited to nineteen categories, this finding leads to a number of additional research issues:

- Do qualitative aspects of the products or the social system result in one specification being more appropriate than another?

- Given the differences in specifications which best fit the adoption process, will a similar variety of models be appropriate for new product forecasting?

- Likewise, can one determine the appropriate level of parameterization when data are available only during the early stages of product development?

Research in new product forecasting using diffusion models has resulted in methods which are appropriate when there are few data, including meta-analysis (Sultan, Farley and Lehmann 1990) or international analogy (Gatignon, Eliashberg, and Robertson 1989). As more observations become available, forecasts can be improved or model parameters can be updated via Bayesian estimation or feedback filters (Mahajan, Bretschneider and Bradford 1980; Bretschneider and Mahajan 1980; Lenk and Rao 1990; Vanhonacker 1990; Vanhonacker, Lehman and Sultan 1990). Such techniques generally assume a unique underlying diffusion process structure or model. The results reported here would suggest that model structures in addition to parameter estimates will vary from one product to another and may need to be adapted as more observations become available. Research investigating the required level of structural adaptation would be desirable.

The incorporation of price into the diffusion process is not unique to this research. Our study expands upon previous work by explicitly considering price elasticity dynamics, the sensitivity of elasticity estimates to prices adjusted or unadjusted for consumer income, and three alternative specifications of price (two nonseparable, one separable) in diffusion models. The results reported confirm the finding that price plays a role in the diffusion of innovations. Unlike empirical research cited earlier, price is found to play a role even for some low-priced durables (e.g., water pulsators, calculators, bedcovers) in addition to medium priced durables (e.g., vacuum cleaners, disposers) and high-priced durables (e.g., televisions, room air conditioners, refrigerators).

For a majority of the categories studied, elasticities are estimated to have varied over the lifecycle. In general, the adoption process is better modeled when price is operationalized to reflect indirect substitution or household income. Irrespective of the definition of price, the direction of price elasticity dynamics appears to vary on a category-specific basis; the hypothesis that elasticities increase over the adoption lifecycle is rejected. Though exploratory in nature, this research generally supports propositions suggested by the integration of economic and diffusion theories. Substitution appears to influence adoption elasticities during the later stages of the lifecycle for those categories facing competitive decline: elasticities increase. As products become necessities, elasticities generally fall or are close to zero throughout the adoption lifecycle. The manner in which price affects the diffusion process (via external influence, internal influence, or both) appears to be either category specific or not critical in terms of estimating elasticity dynamics. The role of product characteristics and related qualitative factors merits greater attention in future research.

Despite the number of research questions raised, the findings reported have several managerial implications: optimal pricing strategies focusing on first purchasers should not necessarily assume constant price elasticities over time; they should also consider the time path of elasticity dynamics as following a number of potential patterns. Competition and the degree to which a category is perceived as a necessity appear to affect elasticity dynamics and magnitudes. Efforts to integrate dynamic elasticities into normative diffusion research would be desirable. For managers interested in understanding the effect of price on product class development, this research implies that income-adjusted prices should be taken into consideration (as they explain consumer adoption decisions better than unadjusted prices), but without assuming that price is only relevant for relatively expensive products or those which represent a high percentage of household budgets.

Given the exploratory nature of the research reported here, additional studies over a larger number of products and/or model specifications which incorporate qualitative aspects of products would be useful. These might include a more direct integration of income (e.g. as in Horsky 1990 or Jedidi, Eliashberg and De Sarbo 1989) across economies with widely different income distribution characteristics. Empirical and normative studies on the effects of category-level distribution or supply restrictions (Jones and Ritz 1987; Jain, Mahajan, and Muller 1990), competition (see, for example, Eliashberg and Jeuland 1983), advertising (Horsky and Simon 1983; Simon and Sebastian 1987), and geographic diffusion (Mahajan and Peterson 1979) when elasticities are dynamic may prove critical for some industries. For example, different elasticity dynamics in distinct geographic regions may affect the choice of market to enter first and the level of pricing in each market after entry (assuming these can be separated). Likewise, the incorporation of dynamic elasticities in repeat/replacement purchase models (Lilien, Rao and Kalish 1981; Mahajan, Wind and Sharma 1983; Olson and Choi 1985; Kamakura and Balasubramanian 1987; Norton and Bass 1987; Rao and Yamada 1988) is a logical extension of this research.

Finally, Narasimhan (1989) shows that price expectations can play an important role in new product adoption, especially for durables with shorter lifecycles or rapid learning on production costs. Expectations formed by, and strategic behavior on the part of, potential adopters may affect the dynamics of elastic responses. Large price drops today may create expectations of further cuts tomorrow. Decisions to forestall adoption may yield different or lagged elastic responses as a category matures. Empirical research in this area for categories likely to experience such behavior would be a useful extension of this study.

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Figure 1. Category penetration (F(t)/M(t)), Price $\left(P(t), \bar{P}(t)\right)$, and First Adoptions $\left(f(t), \hat{f}(t)\right)$ versus age (A(t))

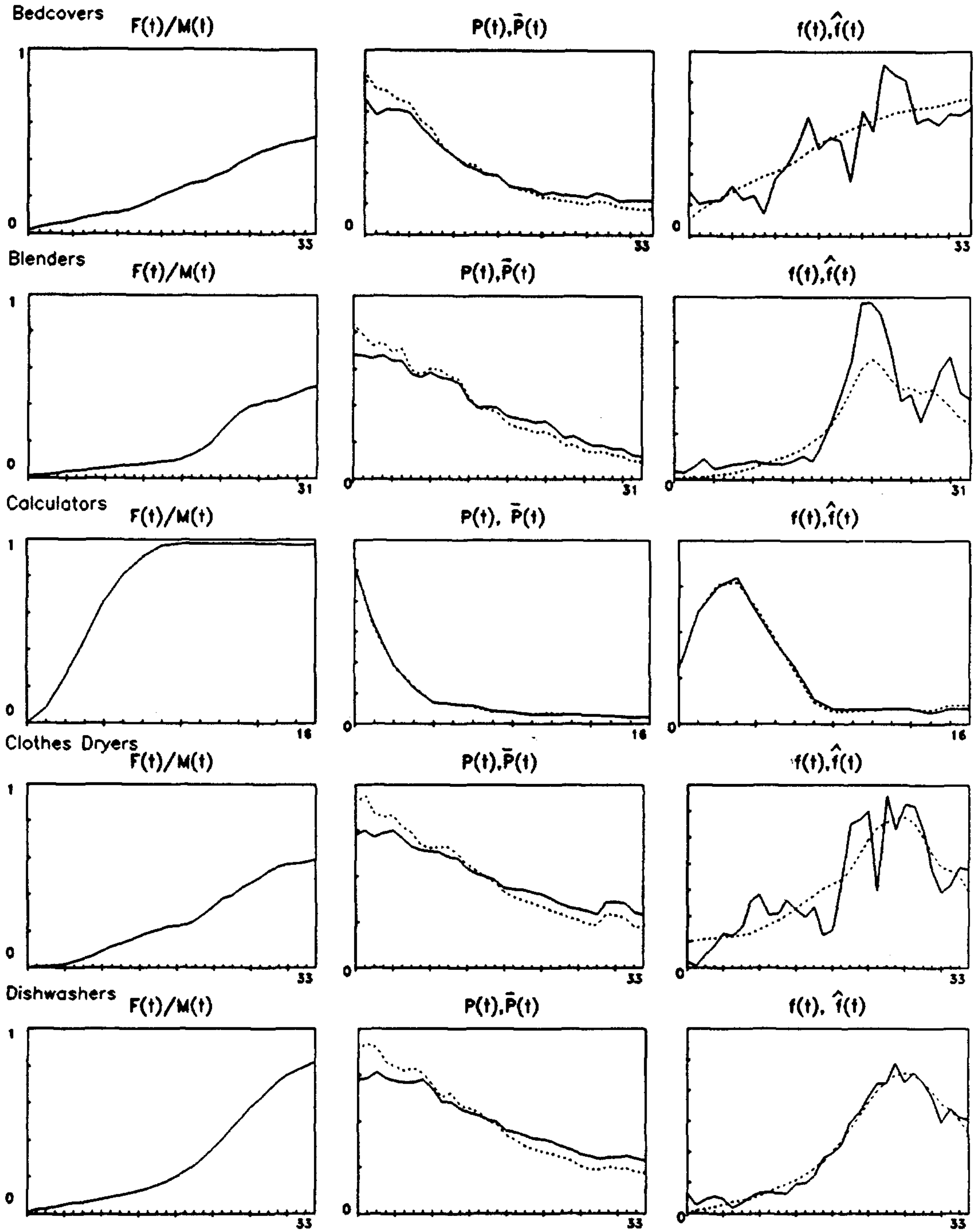

Figure 1. Category penetration (F(t)/M(t)), Price $\left(P(t), \bar{P}(t)\right)$, and First Adoptions $\left(f(t), \hat{f}(t)\right)$ versus age (A(t)); continued

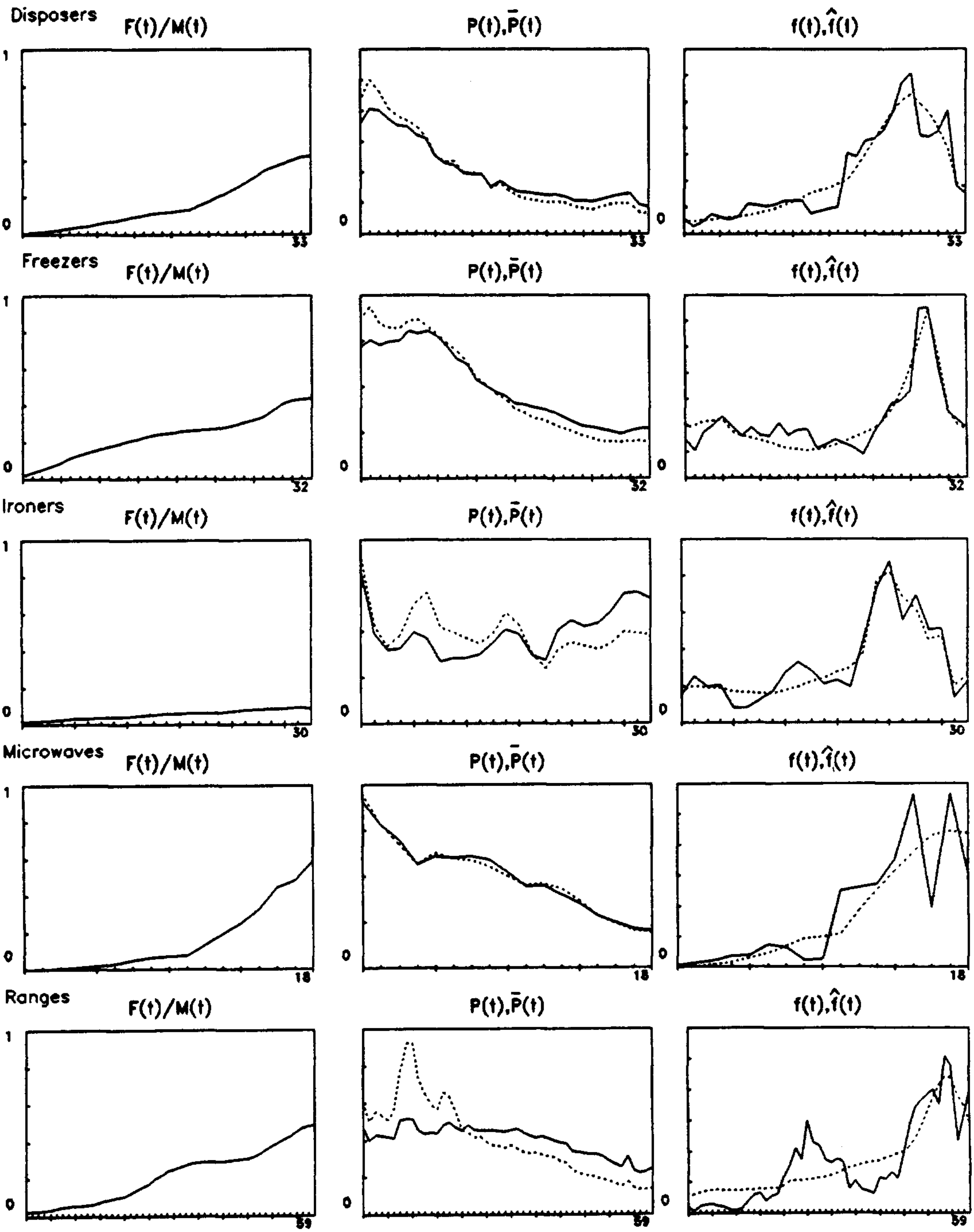

Figure 1. Category penetration $(F(t)/M(t))$, Price $\left(P(t), \overline{P}(t)\right)$, and First Adoptions $\left(f(t), \hat{f}(t)\right)$ versus age $(A(t))$; continued

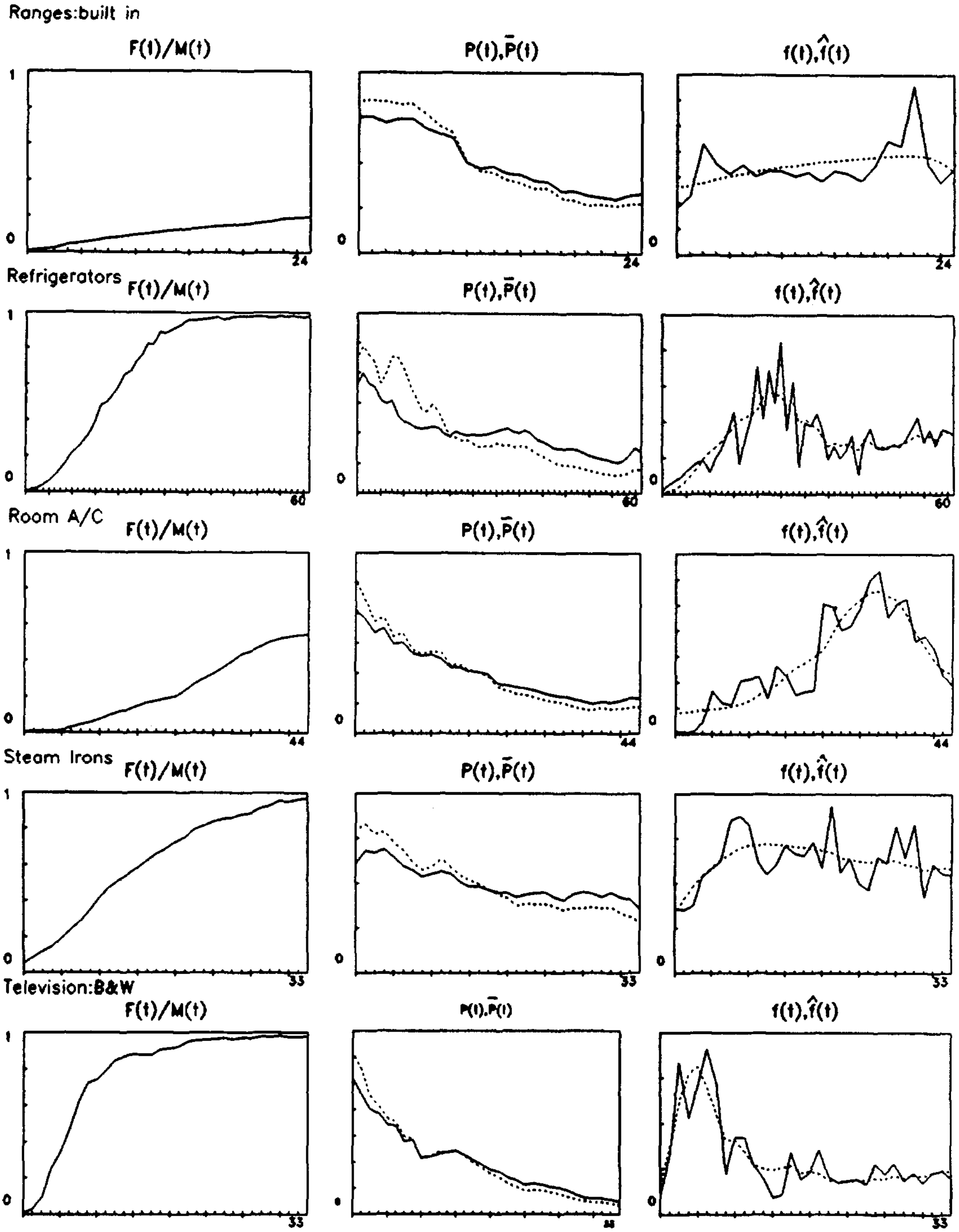

Figure 1. Category penetration (F(t)/M(t)), Price $\left(P(t), \bar{P}(t)\right)$, and First Adoptions $\left(f(t), \hat{f}(t)\right)$ versus age (A(t)); continued

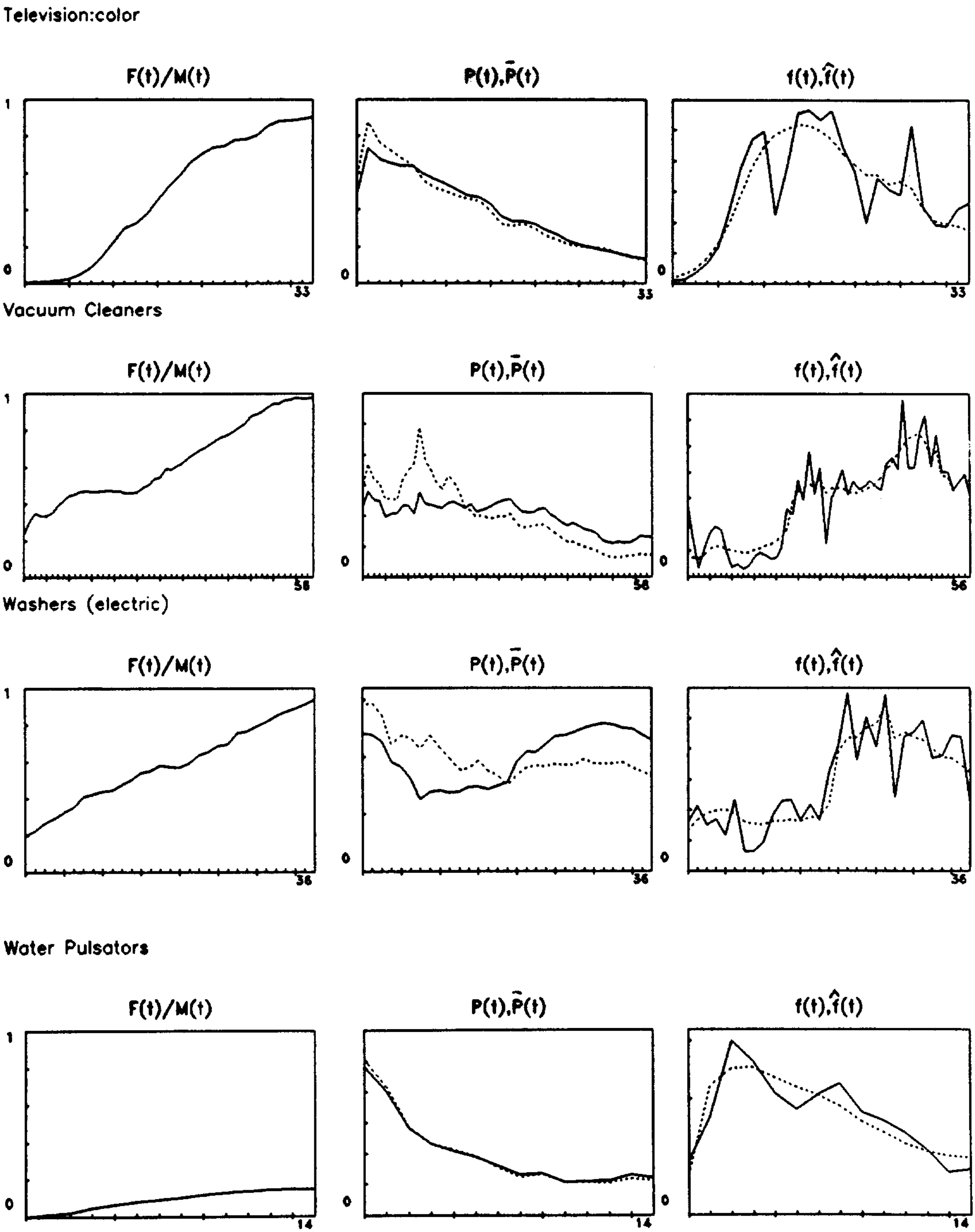

Figure 2. Study Methodology

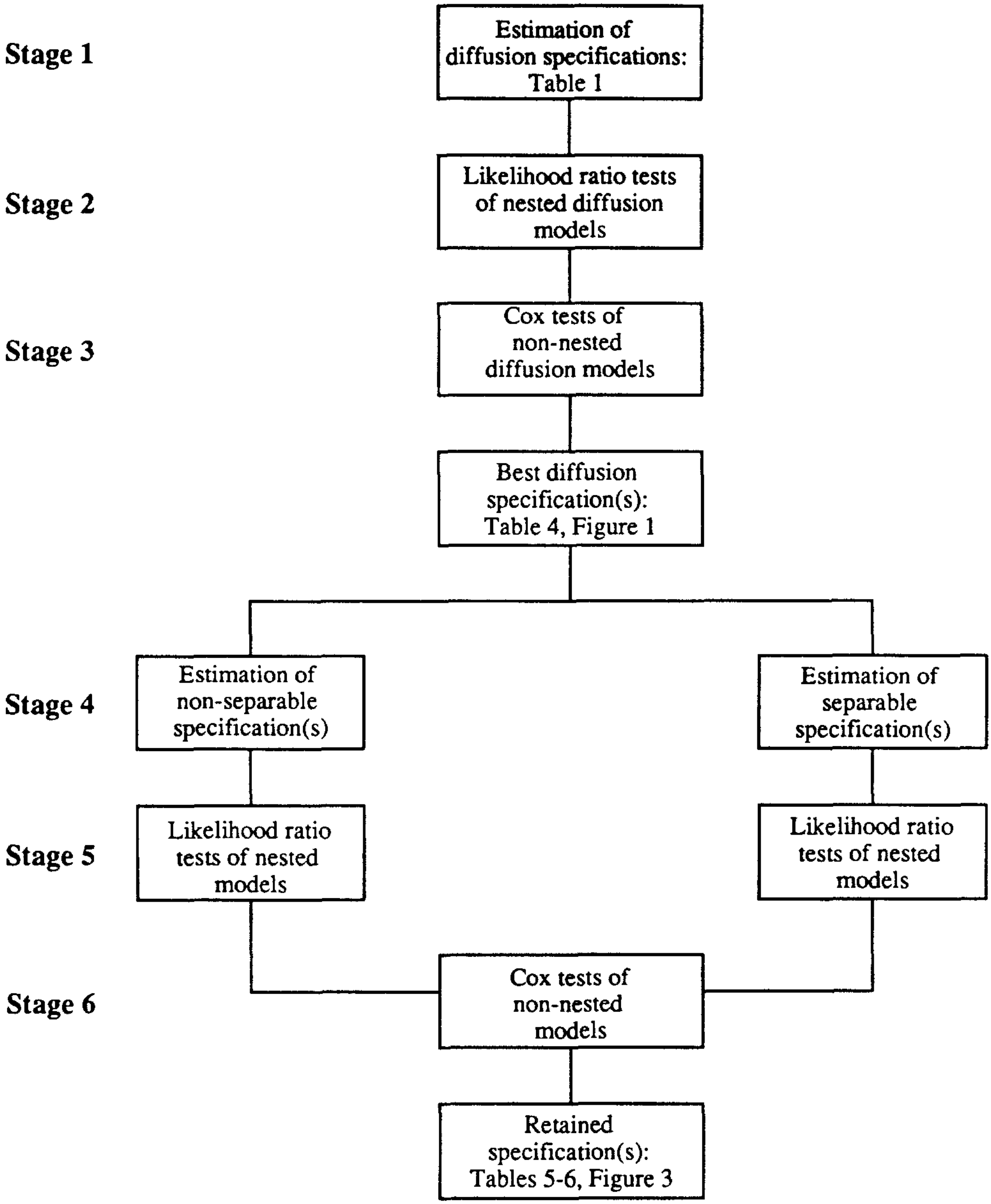

Figure 3. Retained Price Specification and Actual Adoptions versus Category Age.

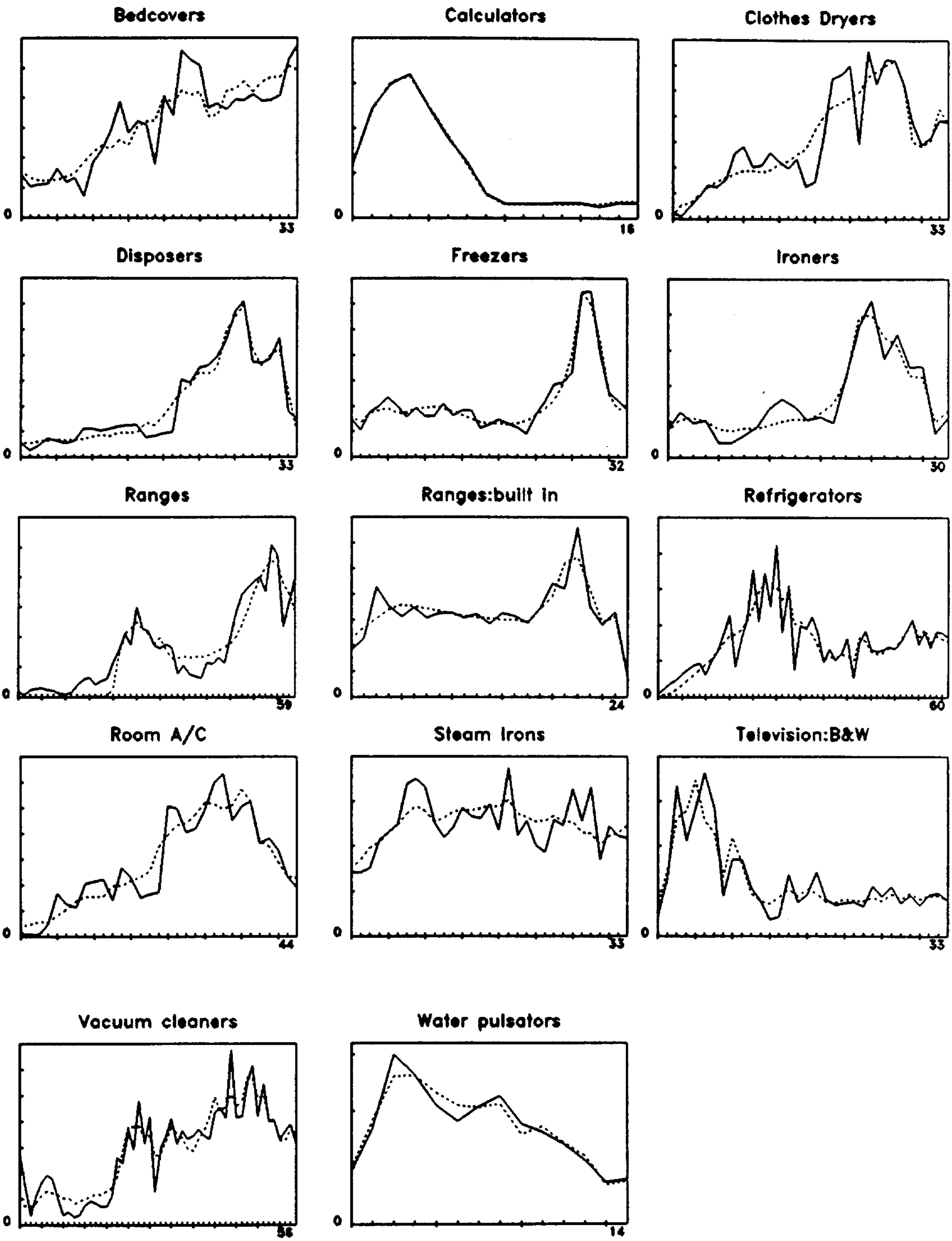

Table 1. Hierarchy of Alternative Diffusion Model Specifications
(category subscript i is omitted)

Model #	Number of Parameters	Specification	Model Nested In
1	5	$f(t)=\left(a+b\left(\frac{F(t)}{cM(t)}\right)^{(1+d)}\right)(cM(t)-F(t))^{(1+e)}$	-
2	4	$f(t)=b\left(\frac{F(t)}{cM(t)}\right)^{(1+d)}(cM(t)-F(t))^{(1+e)}$	1
3	4	$f(t)=\left(a+b\left(\frac{F(t)}{M(t)}\right)^{(1+d)}\right)(M(t)-F(t))^{(1+e)}$	1
4	4	$f(t)=\left(a+b\left(\frac{F(t)}{cM(t)}\right)^{(1+d)}\right)(cM(t)-F(t))$	1
5	4	$f(t)=\left(a+b\left(\frac{F(t)}{cM(t)}\right)\right)(cM(t)-F(t))^{(1+e)}$	1
6	3	$f(t)=a(cM(t)-F(t))^{(1+e)}$	2, 5
7	3	$f(t)=b\left(\frac{F(t)}{M(t)}\right)^{(1+d)}(M(t)-F(t))^{(1+e)}$	2, 3
8	3	$f(t)=b\left(\frac{F(t)}{cM(t)}\right)^{(1+d)}(cM(t)-F(t))$	2, 4
9	3	$f(t)=\left(a+b\left(\frac{F(t)}{M(t)}\right)^{(1+d)}\right)(M(t)-F(t))$	3, 4
10	3	$f(t)=b\frac{F(t)}{cM(t)}(cM(t)-F(t))^{(1+e)}$	2, 5
11	3	$f(t)=\left(a+b\frac{F(t)}{M(t)}\right)(M(t)-F(t))^{(1+e)}$	3, 5
12	3	$f(t)=\left(a+b\frac{F(t)}{cM(t)}\right)(cM(t)-F(t))$	4, 5
13	2	$f(t)=a(M(t)-F(t))^{(1+e)}$	6, 7,
14	2	$f(t)=a(cM(t)-F(t))$	6, 8,
15	2	$f(t)=b\left(\frac{F(t)}{M(t)}\right)^{(1+d)}(M(t)-F(t))$	7, 8, 9,
16	2	$f(t)=b\left(\frac{F(t)}{M(t)}\right)(M(t)-F(t))^{(1+e)}$	7, 10, 11
17	2	$f(t)=\left(a+b\frac{F(t)}{M(t)}\right)(M(t)-F(t))$	9, 11, 12
18	2	$f(t)=b\frac{F(t)}{cM(t)}(cM(t)-F(t))$	8, 10, 12
19	1	$f(t)=b\left(\frac{F(t)}{M(t)}\right)(M(t)-F(t))$	15, 16, 17, 18
20	1	$f(t)=a(M(t)-F(t))$	13, 14, 17

TABLE 2: Description of Product Category Data

Product Category	Years	Maximum Percent Penetration	Price-Range (Max.-Min.)[a]	Year of 1st Purchase Peak	Year of Maximum 1st Purchase Peak	Year of Max. Unit Sales Peak
<u>Non-Declining</u>						
Bed Cover	1948-1979	64.2	0.66-0.09	1952	1979	1963
Blenders	1949-1979	52.4	0.59-0.07	1952	1969	1969
Calculators	1972-1987	97.2	1.22-0.05	1975	1975	1975
Clothes Dryers	1948-1979	61.5	3.62-0.86	1952	1970	1973
Dishwashers	1948-1979	43.0	4.33-1.02	1951	1971	1973
Disposers	1948-1979	43.0	2.13-0.28	1951	1973	1979
Freezers	1948-1978	44.9	5.28-1.11	1952	1974	1974
Ironers	1927-1954	9.3	4.79-1.55	1928	1947	1947
Microwaves	1971-1987	59.4	2.76-0.57	1984	1986	1986
Ranges	1925-1977	51.8	7.95-1.16	1929	1973	1973
Ranges: Built-in	1956-1978	19.6	3.17-0.99	1958	1974	1974
Refrigerators	1925-1979	99.9	11.20-1.42	1932	1950	1973
Room A/C	1949-1979	55.5	6.46-0.99	1953	1971	1970
Steam Irons	1949-1979	99.8	0.26-0.09	1956	1966	1978
Television: B & W	1948-1979	99.9	5.91-0.34	1950	1953	1965
Television: Color	1960-1986	90.5	3.85-0.56	1968	1972	1986
Vacuums	1923-1979	99.9	2.80-0.37	1924	1967	1973
Washers (el.)	1926-1961	95.7	4.28-2.17	1927	1947	1956
Water pulsators	1966-1979	14.6	0.28-0.06	1968	1968	1968

a. Measured as percent of average household income, adjusted for inflation.

Table 3: Best Diffusion Model Specification
(significance levels in parentheses; ".00" signifies < .01; SSE are in thousands)

Product Category	a_i	b_i	c_i	d_i	e_i	SSE (.000)	r	BASS SSE	BASS r
Bed Covers	-	0.1002	-	-0.3546	-	4,362	.86	4,440	.86
		(.00)		(.00)					
	0.0124	0.1046	-	-	-	4,440	.86	4,440	.86
	(.00)	(.00)							
Blenders	-	5.54E-14	0.7266	0.7572	2.909	9,193	.93	20,324	.72
		(.97)	(.00)	(.08)	(.25)				
Built-in Ranges	-	0.0746	0.3170	-0.7659		858	.35	967	.09
		(.06)	(.00)	(.00)					
Calculators	0.0915	0.5584	1.007	-0.2506	-	4,026	.99	8,170	.99
	(0.00)	(0.09)	(.00)	(.00)					
Clothes Dryers	0.0224	0.4537	0.6366	1.2160	-	7,224	.86	11,375	.77
	(.00)	(.00)	(.00)	(.00)					
Dishwashers	-	0.351	0.467	0.286	-	498	.99	4,928	.87
		(.00)	(.00)	(.00)					
Disposers	0.0153	0.6117	0.440	1.260	-	2,554	.94	9,574	.75
	(.01)	(.00)	(.00)	(.00)					
Freezers	8.01E-13	7.50E-10	0.4771	10.601	2.5830	1,783	.93	10,110	.49
	(.91)	(.90)	(.00)	(.00)	(.01)				
Ironers	4.4.63E-10	3.19E-08	0.105	3.807	2.524	26	.95	186	.57
	(.82)	(.82)	(.00)	(.00)	(.00)				
Microwave	-	0.389	-	-	-	65,413	.84	63,389	.85
		(.00)							
Television: B & W	-	0.0002	1.1437	-0.5624	0.7280	21,279	.87	41,179	.76
		(.84)	(.00)	(.00)	(.12)				
Television: Color	-	0.2113	1.0216	-0.4229	-	20,289	.86	26,505	.82
		(.00)	(.00)	(.00)					
	-0.0156	0.233	-	-0.5041	-	20,089	.86	26,505	.82
	(.49)	(.00)		(.00)					
Ranges	0.0388	1.012	0.516	5.113	-	5,959	.86	7,896	.80
	(.00)	(.00)	(.00)	(.00)					
Refrigerators	-	0.337	1.045	-	-	10,862	.83	29,481	.74
		(.00)	(.00)						
Room A/C	0.0190	0.4531	0.5781	0.9691	-	4,298	.91	11,352	.74
	(.00)	(.00)	(.00)	(.00)					
Steam Irons	-	0.1091	1.2734	-0.585	-	6,102	.66	23,013	.46
		(.00)	(.00)	(.00)					
Vacuum Cleaners	2.44E-07	1.44E-05	1.041	11.464	1.281	6,034	.91	34,806	.51
	(.76)	(.73)	(.00)	(.00)	(.00)				
Washers	5.10E-10	-	1.453	-	1.818	3,977	.88	7,935	.74
	(.79)		(.00)		(.00)				
Water Pulsators	-	0.20	0.18	-0.81	-	289	.90	1,201	.44
		(.00)	(.00)	(.00)					

Table 4: Retained Price Models (P(t)); significance levels in parenthes; ".00" signifies < .01; SSE are in thousands

Product Category	a	b	c	d	e	h	j	k	SSE	r	χ^2	Form
Bed Covers	-	0.0243	-	-1.1600	-	-1.4330	-	-	3676	0.88	5.5	-
		(.09)		(.00)		(.02)						
	0.0324	-8.53E-04	-	-	-	-1.1656	-	-	3704	0.88	5.8	B
	(.00)	(.97)				(.00)						
	0.0324	-0.0115	-	-	-	-1.1911	-	-	3698	0.88	5.9	E
	(.00)	(.83)				(.00)						
Built-in Ranges	-	1.32E-07	0.219	-0.820	1.547	-3.934	0.608	-0.030	218	0.88	22.6	-
		(.96)	(.00)	(.01)	(.44)	(.14)	(.09)	(.02)				
Calculators	273.010	160.020	0.9840	-0.8298	-0.6553	-0.6120	-	0.0403	464	0.99	20.7	E
	(.11)	(.09)	(.00)	(.00)	(.00)	(.00)		(.00)				
Clothes Dryers	0.0032	0.1836	0.6185	-0.0020	-	2.8880	-0.1748	-	5896	0.89	6.5	B
	(.57)	(.06)	(.00)	(.99)		(.18)	(.02)					
	0.0021	0.4680	0.6363	0.9645	-	-	1.0921	-	6009	0.89	5.9	E
	(.65)	(.00)	(.00)	(.00)			(.24)					
Disposers	0.0058	6.4358	1.5728	2.7553	-	-19.840	0.7076	-	2099	0.95	6.3	I
	(.78)	(.93)	(.78)	(.07)		(.15)	(.17)					
	0.0036	6.2794	2.4137	2.1808	-	-9.2167	-	0.0118	2072	0.95	6.7	I
	(.85)	(.94)	(.85)	(.08)		(.09)		(.15)				
	0.0029	2.8308	2.9510	1.6261	-	-	-0.5910	0.0211	2049	0.95	7.0	I
	(.88)	(.93)	(.88)	(.11)			(.09)	(.13)				
Freezers	2.64E-13	7.62E-11	0.4745	7.3343	2.6854	10.3283	-0.4009	-	1005	0.96	17.8	I
	(.91)	(.88)	(.00)	(.01)	(.00)	(.00)						
	3.38E-12	3.18E-10	0.4695	5.7799	2.4257	5.7404	-	-0.0096	953	0.96	19.4	I
	(.89)	(.87)	(.00)	(.02)	(.00)	(.00)		(.00)				
	1.02E-10	2.18E-09	0.4637	3.7108	2.0775	-	0.4875	-0.0212	933	0.96	20.1	I
	(.87)	(.84)	(.00)	(.07)	(.00)		(.00)	(.00)				
Old B & W TV	-	1.61E-07	1.1025	-0.7846	1.4861	-2.5207	0.0719	-	16886	0.90	7.4	-
	-	(.00)	(.00)	(.04)	(.02)	(.05)						
	-	2.86E-06	1.0734	-0.7166	1.2115	-1.9144	-	0.0015	17042	0.90	7.1	-
		(.85)	(.00)	(.00)	(.03)	(.03)		(.06)				
Ranges	0.0143	0.9858	0.5110	4.3664	-	-30.8830	2.3525	-0.0326	3956	0.91	19.7	E
	(.10)	(.00)	(.00)	(.00)		(.03)	(.01)	(.02)				
Room A/C	0.0493	0.2876	0.5781	2.2262	-	-2.1101	-	-	3490	0.93	6.5	E
	(.00)	(.15)	(.00)	(.16)		(.00)						
	-0.0993	0.1673	0.5795	-0.9379	-	-	-	-0.0010	3496	0.93	10.9	I
	(.36)	(.09)	(.00)	(.00)				(.04)				
Vacuum Cleaners	8.34E-09	2.76E-07	1.0647	11.3112	1.6373	-	-0.0650	-	4890	0.93	10.3	E
	(.76)	(.73)	(.00)	(.00)	(.00)		(.00)					
	2.17E-07	7.85E-06	1.0484	13.2361	1.3259	-2.4279	-	-	4952	0.92	9.0	E
	(.74)	(.70)	(.00)	(.00)	(.00)	(.00)						
	7.96E-09	2.61E-07	1.060	10.3740	1.6345	-	-	-0.0015	5079	0.92	9.6	E
	(.77)	(.74)	(.00)	(.00)	(.00)			(.00)				
	1.36E-07	2.22E-06	1.0548	8.8965	1.3534	-1.3392	-	-	5021	0.92	8.2	B
	(.75)	(.73)	(.00)	(.00)	(.00)	(.01)						
	3.06E-08	5.82E-07	1.0530	8.4834	1.4959	-	-0.0298	-	5153	0.92	6.6	B
	(.76)	(.75)	(.00)	(.00)	(.00)		(.01)					
	3.68E-08	8.28E-07	1.0453	8.6055	1.4749	-	-	-5.89E-04	5311	0.92	12.9	B
	(.77)	(.75)	(.00)	(.00)	(.00)			(.02)				
Water Pulsators	-	0.2264	0.1503	-0.9587	-	-1.489	0.3744	-0.0355	115	0.96		-
		(.00)	(.00)	(.00)		(.08)	(.15)	(.09)				

Note: "E" signifies external influence nonseparable, "I" signifies internal influence nonseparable functional form and "B" signifies both or separable functional form.

Table 5: Retained Price Models ($\bar{P}(t)$); significance levels in parentheses; ".00" signifies < .01; SSE are in thousands

Product Category	a	b	c	d	e	h	j	k	SSE	r	x[illegible]	Form
Bed Covers	0.0359	-0.0228	-	-	-	-1.1551	-	-	3345	0.90	9.1	B
	(.00)	(.12)				(.00)						
	0.0495	-0.1024	-	-	-	-1.0105	-	-	3257	0.90	9.9	E
	(.00)	(.14)				(.00)						
	-	0.0138	-	-1.4602	-	-1.4617	-	-	3305	0.90	8.9	B
		(.08)		(.00)		(.00)						
Built-in Ranges	-	1.0858	0.1972	-0.6844	-0.2449	-	0.1297	-0.0105	242	0.87	20.2	-
		(.62)	(.00)	(.00)	(.30)		(.01)	(.00)				
	.1416	-0.0285	.1978	-	-0.0121	-3.1038	.528	-0.024	232	0.87	21.1	B
	(.79)	(.92)	(.00)		(.97)	(.14)	(.03)	(.01)				
	.0035	.0221	.1982	-	.2368	-	.3171	-0.026	221	0.88	22.2	E
	(.78)	(.76)	(.00)		(.54)		(.00)	(.00)				
Calculators	358.91	202.48	.9826	-0.8075	-0.6797	-0.5763	-	.0401	478	0.99	20.3	E
	(.16)	(.10)	(.00)	(.00)	(.00)	(.00)		(.00)				
Clothes Dryers	-0.1884	.2576	.6266	-0.9499	-	-	-	-0.0014	4918	0.91	12.3	I
	(.42)	(.26)	(.00)	(.00)				(.20)				
Disposers	.0279	2.4879	.422	18.0358	-	-0.4356	-	-0.0032	1219	0.97	23.7	E
	(.00)	(.00)	(.00)	(.00)		(.86)		(.00)				
Freezers	.0031	.0037	.4402	-1.7121	.2165	-5.4643	.7494	-0.0242	698	0.97	29.1	I
	(.42)	(.58)	(.00)	(.00)	(.20)	(.02)	(.00)	(.00)				
Ironers	4.62E-12	3.57E-10	.1078	3.6275	3.1288	4.4646	-1.6903	.0799	18	0.97	8.2	E
	(.83)	(.84)	(.00)	(.00)	(.00)	(.23)	(.19)	(.21)				
	1.11E-11	9.42E-10	.1063	3.686	3.0126	-18.360	1.7897	-0.4176	18	0.97	8.8	I
	(.82)	(.81)	(.00)	(.00)	(.00)	(.03)	(.03)	(.03)				
Ranges	0.0886	0.9335	0.5182	3.9402	-	-52.420	1.6385	-	3127	0.93	31.0	E
	(.00)	(.00)	(.00)	(.00)	(.30)	(.02)	(.02)					
Refrigarators	-	0.3624	1.0074	-	-	-	-0.0371	0.0004	8822	0.86	10.4	-
		(.00)	(.00)				(.01)	(.05)				
	-	0.3678	1.0111	-	-	-0.5788	-	-	8966	0.86	9.6	-
		(.00)	(.00)			(.00)						
Room A/C	-46.2330	46.301	.5815	-0.9998	-	-	-0.0475	-	3503	0.93	6.3	B
	(1.00)	(1.00)	(.00)	(.42)			(.01)					
	.0484	.3143	.5748	2.6645	-	-1.5985	-	-	3446	0.93	6.9	E
	(.00)	(.10)	(.00)	(.21)		(.00)						
	-0.0616	.1301	.5733	-0.9034	-	-	-	-8.99E-04	3434	0.93	7.0	I
	(.41)	(.05)	(.00)	(.00)				(.01)				
Television B & W	-	2.19E-06	1.0779	-0.8171	1.2282	-2.0389	.0532	-	17595	0.89	6.1	-
		(.87)	(.00)	(.00)	(.05)	(.04)	(.09)					
	-	1.92E-05	1.0538	-0.7526	1.0211	-1.5902	-	.0011	17618	0.89	6.0	-
		(.83)	(.00)	(.00)	(.04)	(.04)		(.09)				
Vacuum Cleaners	.0001	.049	.9893	99.1951	.6763	-0.4905	-	-9.86E-04	4418	0.93	16.2	E
	(.82)	(.75)	(.00)	(.00)	(.14)	(.32)		(.03)				
	.0001	.0187	.9981	60.3392	.6776	-	-0.0527	-	4525	0.93	15.0	E
	(.66)	(.64)	(.00)	(.01)	(.01)		(.00)					
Water Pulsators	-	0.2274	0.1492	-0.9663	-	-1.4921	0.3776	-0.0359	92	0.97	16.0	-
		(.00)	(.00)	(.00)		(.04)	(.08)	(.04)				

Note: "E" signifies external influence (nonseparable),
"I" signifies internal influence (nonseparable),
and "B" signifies both (separable functional form).

Table 6. Summary of Elasticity Dynamics

Elasticity Dynamics (in absolute value)	Weak Support	Strong Support
Constant	Blenders, Color Televisions, Microwaves Ovens, Dishwashers, Washers*, Steam Irons, (Ironers*, Refrigerators).	Bed Covers
Decreasing		B & W Televisions*, Calculators, Ranges
Increasing	Room Air Conditioning, (Vacuum Cleaners*)	Clothes Dryers, Disposers*, Vacuum Cleaners*
Increasing then decreasing	Refrigerators	
Decreasing then increasing	Built-in Ranges	Freezers*, Water Pulsators, (Built-in Ranges)
Inconclusive	(Freezers*)	Ironers*, (Disposers*)

Note: Categories in parentheses reflect results derived from prices not adjusted for income changes, P(t), which are not classified in the same cell as prices adjusted for income, $\overline{P}(t)$; clothes dryers are found to have positive elasticities over the range of A(t) when prices are not adjusted for income; "*" signifies a category facing declining penetration.

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