"CHOOSING AMONG DIFFUSION MODELS: SOME EMPIRICAL GUIDELINES"

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Some Empirical Guidelines

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Abstract

A number of econometric diffusion models have been suggested in the marketing literature to assist researchers and managers in better understanding the implications of both short-run and long-run adoption processes. Is there a "best" diffusion model? This paper responds to calls for an integration and evaluation of both parsimonious and more complex flexible-form diffusion models. Our study focuses on models which find their origins in the mixed-influence model proposed by Bass (1969). First purchase data collected for 19 durable goods are used to evaluate 24 alternative diffusion models. Two approaches are used for the systematic comparison. The first is a meta-analytic study of all categories pooled together. This procedure allows us to conclude, for example, which among all three-parameter diffusion models are likely to provide, on average, the highest explanatory power. The second is an econometric approach which determines, for each category individually, the best fitting model based on likelihood ratio tests (nested and non-nested comparisons). These best models are then examined in terms of parameter plausibility. Across the two methods, a number of guidelines are produced which stand to improve the future use and choice of diffusion models in forecasting, theory testing and normative studies.

Introduction

In their recent review of the literature, Mahajan, Muller and Bass (1990) note the expanding importance of new product diffusion models in academic research and applied industrial settings (telecommunications, consumer durable goods, education, retail services, medical services and equipment). Interest among researchers in studying the diffusion of innovations has led to a proliferation of various mathematical models which have been designed for forecasting, descriptive and normative studies. As the number of new models developed over the past thirty years has generally out paced empirical applications/validation, Mahajan, Muller and Bass (p. 21) note the need for additional studies which address the following issues: (1) the need "to examine various diffusion models systematically to identify the one that best fits the data"; (2) the need to empirically validate the relevance of models used in normative studies, as these are "simply working hypotheses"; and, more generally, (3) the need "to identify conditions under which diffusion models work or do not work".

This paper presents empirical research that begins to address these issues. In particular we systematically compare diffusion models based on their ability to explain the long-run first-purchase, or adoption processes for consumer durable goods. In doing so, we consider complex models, called "flexible", which have been developed to explain various asymmetric diffusion patterns, including adoption curves with slow take-off periods. Since flexible diffusion models can shed light on the length of the take-off period (i.e. these models can produce patterns with either long or short left-hand tails of the new product adoption curve), this research stands to address two additional questions posed by Mahajan, Muller and Bass (p.20): (1) " How much long-term forecasting accuracy is provided by flexible models, in comparison with basic diffusion models such as the Bass (1969) models, when controlled for the number of parameters?, and (2) "... how can parameters in these models be calibrated prior to launch for long-term forecasting? Further empirical work related to these questions is desirable." In addition to comparing existing diffusion models (basic and flexible), this study responds to the call for the empirical study of models which integrate multiple phenomenon, including dynamic market potentials, non-uniform interpersonal influences, and heterogeneous adopter populations (Gatignon and Robertson 1985; Rao 1984; Easingwood, Mahajan and Muller 1983; Kamakura and Balasubramanian 1988; Jeuland 1981).

Overview of The Methodology

Using first purchase (adoption) data for nineteen durable goods, twenty-four alternative diffusion models developed over the past three decades are systematically compared using two research methodologies. The first methodology is a meta-analytic approach which has a goodness-of-fit measure for its dependent variable. Two basic questions are addressed:

(1) which model best explains diffusion patterns when the models are limited to one, two, three or four parameters?

(2) what number of parameters is typically required to model the diffusion process (from one to five parameters)?

In addressing these questions, we can conclude, for example, which of all suggested three parameter models is likely to best explain adoption data. Further, we can determine if three parameters is generally enough to explain the process, versus five parameters (how much more explanatory power do the additional parameters contribute?).

The second methodology is used to cross-validate the findings of the first, and provide insights into the range and plausibility of diffusion parameters. Pairwise tests of nested and nonnested models are used to determine, for a given category individually, the "best" model. The best model, may, however, yield implausible parameter estimates, in which case a "second best", yet interpretable model is determined. This procedure indicates whether the results from the first study accurately predict the best specifications for any given category (a within sample validity test). By comparing best models across categories, we can generate a number of conclusions with respect to parameter requirements and the appropriateness of various models in explaining the data.

The goal of these two studies is to produce general guidelines covering the selection of model specifications. As discussed later in the paper, a number of patterns emerge from the two analyses. In particular, clear guidelines are presented as to the appropriate selection of models to capture long-run diffusion processes. The results have direct implications for forecasters, who are interested in using models either as bench marks for pre-launch forecasts, or for econometric forecasts using the most reasonable, yet parsimonious, functional forms. The guidelines also provide a basis upon which future normative and theoretical studies can be conducted. These topics are explored in greater detail following a discussion of the models compared in this paper, and the empirical results generated from the two methodologies.

Empirical Diffusion Models

Two broad categories of models are considered: (1) Bass-type diffusion models (twenty specifications), and other diffusion models (four specifications). We primarily focus attention on models which find their its roots in the model proposed by Bass (1969). As noted by Mahajan, Muller and Bass, the Bass model has received widest acceptance in the field of marketing.

Bass-Type Diffusion Models

Generalizing models developed by Fourt and Woodlock (1960) and Mansfield (1961), 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)) and the total number of potential adopters M:

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

where the estimated constants, a_0 and b_0, have been labeled the coefficients of innovation and imitation or of external or internal influence, respectively. The Bass model assumes 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, reflected in the coefficient of imitation. Following diffusion theory pioneered by Rogers (1983) and extended by Robertson (1967) in marketing, early adopters (who are often opinion leaders) 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). This basic diffusion model has seen wide application in descriptive and forecasting studies for consumer and industrial innovations.

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). The inclusion of these modifications is especially critical when studying long-run diffusion processes. The simultaneous modeling of non-uniform influences, heterogeneous adopter populations, and dynamic potentials has yet to be considered in the literature.

In order to consider the various modifications made to equation 1, we begin by defining a five parameter diffusion specification from which nineteen sub-models are nested:

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

where a_i, b_i, c_i, d_i, e_i are constants. Equation (2) belongs to a class of flexible diffusion models which allows for a variety of non-symmetric diffusion patterns (see Mahajan, Muller and Bass 1990). Easingwood, Mahajan and Muller (1981, 1983) control for nonuniform interpersonal influence (NUI) by incorporating the constant parameter d_i. Jeuland (1981) controls for heterogeneous adopter populations via the parameter e_i. Kamakura and Balasubramanian (1988) and Jain and Rao (1990) use the parameter c_i to adjust the market potential M(t), set exogenously as the time-varying number of households wired with electricity, for the non-adoption by certain households; c_i measures, therefore, the ultimate penetration level of households. Of the nineteen models nested within equation (2) (see Table 1 for model specifications), the following models have been previously examined in the literature (while assuming either static or dynamic market potentials):

Models	Parameters					Authors
8	a	b	c			Kamakura and Balasubramanian (1988)
10	a	b		d		Easingwood et al. (1983)
11	a	b			e	Jeuland (1981)
13		b	c			Kamakura and Balasubramanian (1988)
14	a	b				Bass (1969)
15		b		d		Easingwood et al. (1981)
17	a		c			Kamakura and Balasubramanian (1988)
19		b				Mansfield (1961)
20	a					Fourt and Woodlock (1960)

In addition to these previously investigated models, a number of integrated models are specified. For example, Model 9 in Table 1 assumes that nonuniform interpersonal influence is present, that the market potential varies over time, that external influences are not present, and that the diffusion process is over a heterogeneous adopter population (a hybrid between Mansfield, Easingwood et al. and Jeuland specifications). The appropriate (or best fitting) specification for a given category is largely an empirical issue. For example, diffusion may have occurred in a symmetric fashion due to uniform interpersonal influence. In such cases, d_i will not be required in the underlying diffusion specification (for the category concerned).

Other Models

In addition to the twenty Bass-type models listed in Table 1, we will also consider the following specifications which, although similar to the Bass model due to a saturating market potential and a coefficient of internal influence, are not direct derivatives of or improvements made upon equation (1):

$$f(t) = b_i\left(\frac{F(t)}{M(t)}\right)\left(\frac{\ln M(t)}{F(t)}\right) \tag{3}$$

$$f(t) = b_i\left(\frac{F(t)}{M(t)}\right)(M(t) - F(t))^2 \tag{4}$$

$$f(t) = b_i\left(\frac{F(t)}{M(t)}\right)(M(t) - F(t))^{g_i} \tag{5}$$

$$f(t) = b_i\left(\frac{F(t)}{M(t)}\right)\frac{(M(t) - F(t))}{t} \tag{6}$$

Equation (3) is the Gompertz curve (see Hendry 1972, and Dixon 1980) and has been applied to consumer durables and agricultural innovations; Equation (4) is the Floyd (1962) model and has been applied to industrial innovations; Equation (5) in proposed by Nelder (1962) and has been applied to agricultural innovations (g_i is a constant; see also McGowan 1986, Von Bertalanffy 1957 and Richards 1959); Equation (6) is proposed by the Stanford Research Institute (SRI; Teotia and Raju 1986) and has been applied to innovations in the energy sector. We consider these models while understanding that they represent alternatives to the parsimonious formulations of the Bass model (one or two parameters). Lacking theoretical foundations, higher order or more complex formulations of Equations (3) to (6) are not investigated.[1]

The Data

In order to focus on the long-run diffusion process the underlying data need to span multiple stages of the adoption cycle (introduction, growth, peak, and decline). Nineteen categories were selected among over seventy categories of consumer durables which were screened for the existence of data on first purchases (adoption); only nineteen met the criteria of including multiple lifecycle stages. Most empirical diffusion studies of consumer durables report similar, but fewer categories than this as the focus is on model illustration, not testing relative performance across models. In our case, the nineteen categories are a convenience sample based on a broad search over of secondary data sources. The following data were collected for each category: the number of households wired for electricity (M(t)), and the number of wired households having adopted at least one unit of the product category (f(t) and F(t)); see Figure 1 and Table 4 for a list of the categories. The years studied are based on the availability of annual cross-sectional surveys of wired household penetration and include first adoption of households based on the purchase of either new or used durables. With the exception of Kamakura and Balasubramanian (1988), previous studies of consumer durables have generally relied on early sales data, as opposed to first purchase or adoption data. 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 greater several decades later) or an ultimate peak/spike. Figure 1 illustrates the variance in shapes of the adoption curve across the categories studied.

Estimation and Selection Procedure

Given the inherent nonlinearity in a larger number of the diffusion models tested, nonlinear least squares (NLS) is used to estimate each model. One advantage of NLS is that standard errors can be estimated for individual coefficients (Srinivasan and Mason 1986). Using annual data for each of the alternative diffusion models may introduce, however, a time interval bias (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 to compare performance across products, the results reported should be insensitive to such biases. Mahajan, Muller and Bass (p. 9) note that parameter estimates do not greatly differ across estimation methods which control for or ignore such biases.

Comparative Study #1: A Meta-Analytic Approach

Our first study treats each model-category combination as an independent observation (study). Focus is placed on the success of each model in statistically explaining the diffusion process. We operationalize "success" to be the correlation between predicted versus actual values (r) which is a standard measure across all observations. Pooling across observations, we can test for mean differences across specifications, given that all models were tested on every category. As correlations are insensitive to degrees of freedom, care must be taken to avoid comparing model specifications with different numbers of parameters each. Given this concern, two analyses are needed: the first tests for the best model among those having the same number of parameters. The second analysis explores the relative benefit of using additional parameters to explain the diffusion process.

To test the relative performance of models having a given number of parameters, j, we can specify the following analysis of variance (ANOVA) dummy variable regression function:

$$r_j = \alpha_0 + \beta_k M_K, \quad j = 1,...,4 \tag{3}$$

where r_j is the correlations between fitted and actual values for models having j parameters each, α_0 is the intercept constant which reflects the mean r_j of the diffusion model having the highest r_j among the models with j parameters, $\mathbf{M_k}$ is a vector of dummy variables indicating competing models with lower mean values of r_k, and β_k is a vector of constants associated with $\mathbf{M_k}$ and measures the difference of fit between the best fitting model and model k. Sultan, Farley and Lehmann (1990), in a meta-analysis of various estimates of the coefficient of external and internal influence in the Bass model, adjust their basic ANOVA model for four factors: (1) the estimation procedure (e.g. OLS versus NLS), (2) the type of innovation (e.g. medical versus consumer durables) and country of origin, (3) the variables included in each model studied (e.g. marketing mix variables), and (4) data re-use across studies (Pedhazur 1982, p. 555-7). As all models are estimated using the same nonlinear least squares procedure, we need not control for estimation effects.[2] Likewise, all products studied come from the same general category (consumer durables in the United States) and all models are estimated using the same independent variables (F(t) and M(t)). As we test differences in fit across model structures, we too need to consider data re-use across models; we do so by including eighteen category dummy variables, which reduces the degrees of freedom in the basic ANOVA model:

$$r_j = \alpha_0 + \beta_k M_K + \delta_l CAT_l, \quad j = 1,...,4 \tag{4}$$

where $\mathbf{CAT_l}$ is a vector of category dummy variables and δ_l is a vector of constants associated with the dummies.[3] Four separate ANOVA models are estimated (j=1,..,4), one for each level of parameterization. Columns 6 and 7 of Table 3 show the results of the four ANOVA regressions; the results can be summarized as follows:

- Of the one parameter models, the Mansfield model (Model 19) with the coefficient of internal influence, b_i, is the best fitting Bass-type model; compared to the other one parameter models, there is no statistical difference between the Mansfield model and the Floyd model, which might be expected given their similar functional forms.

- Of the two parameter models, the inclusion of the market potential coefficient, c_i (Model 13, Kamakura and Balasubramanian), provides the highest absolute and incremental fit among Bass-type models; the contribution of this parameter is marginally significant ($p > .10$) compared to models which add a_i, d_i, or e_i; the best 2 parameter Bass-type model is statistically equivalent to the 2 parameter Nelder specification.

- Of the three parameter models studied, the model which includes b_i, c_i, and d_i (adding the NUI parameter, Model 6) provides the best fit, which represents a marginally significant $(p \leq .25)$ improvement over models which add either the coefficient of innovation ai or the heterogeneous adopter coefficient, e_i.

- Of the four parameter models, the best model either includes a_i, b_i, c_i, and d_i (Model 2), or b_i, c_i, d_i and e_i (Model 3); these two specifications yield statistically equivalent results, yet are better than the other alternatives ($p < .05$).

Across the first two ANOVAs, we can conclude that Bass-type models are not outperformed by non-Bass parsimonious models. Restricting ourselves, therefore, to Bass-type specifications, an interesting pattern emerges. In an incremental sense, the four ANOVAs would indicate an order of importance across parameters: first, the internal influence coefficient b_i (Model 19, r=.59); second, the market potential coefficient, c_i (Model 13, r=.74); third, the NUI coefficient, d_i (Model 6, r=.81), and (4th) either the external influence coefficient, ai, (Model 2, r=.86) or the heterogenous adopter coefficient, e_i (Model 3, r=.84); the choice between models 2 and 3 might be made based on some non statistical criteria, including parameter plausibility, or the ease of calibrating parameters prior to launch. Often, managers may have informed guesses, or external estimates of the ultimate penetration levels, c_i (see Tigert and Farivar 1981; Mahajan and Peterson 1978; and Mahajan, Jain and Malhotra 1979). If one were to know, in advance, the ultimate penetration level, c_i, then the order of parameter importance remains unchanged: first b_i, then d_i, then either a_i or e_i (Table 2, column 4). The choice between including either a_i and e_i might be made on theoretical grounds; for example, the model may require a positive intercept, hence the need for a_i.

From the four ANOVAs above, it would appear that moving from the best one parameter model to a two parameter model is beneficial (r=.59 versus r=.74); the same can be said for moving from the best two parameter model to the best three parameter model (r=.74 to r=.81). The additional explained variance gained by adding a fourth parameter diminishes, but is nevertheless consequential (from r=.81 to r=.86). Moving to five parameters does not seem justified (from r=.864 to r=.867). The appropriate number of parameters may vary on a category specific basis, or be general. This issue, as well as concerns for parameter plausibility, is taken up in the second study reported below.

Comparative Study #2: Econometric Approach

The goal of the econometric approach is to rigorously compare the alternative models in order to determine the best fitting model for each category individually and to ascertain, if possible, common patterns across the categories. This will shed light on: (1) the number of parameters required to model the diffusion process, and (2) the types of effects (parameters) that are most important to include in the model, and (3) which specifications consistently are found "the best" among the alternatives, or those which consistently fail to best fit any of the categories studied. In addition to considering fit statistics as in the meta-analysis above, consideration is also given to the plausibility of the parameter estimates.

Given the results of the meta-analysis, we will focus on the twenty alternative Bass-type diffusion models. In order to compare the models, a four stage procedure is followed. 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. Model 20 is, for example, nested in Models 14, 17 and 18 which are, themselves, respectively, nested in Models (8, 10, 11), (6, 12), and (9, 12) which, in turn, are nested versions of less parsimonious specifications. For a constrained model to be eliminated, the chi-squared distributed likelihood ratio test statistic is required to indicate a significant difference, at the α = .05 level, between the full and constrained models. When there is no significant difference between two models, the constrained (more parsimonious) 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 which remain in competition, usually having the same number of parameters. 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. α = .05 significance level), models are eliminated in favor of parsimonious alternative specifications when the chi-squared distributed test statistic is not significant. As noted by Judge et al. (1985), the Cox test may yield inconclusive results, in which case both models are retained. In practice, nonnested tests are generally performed across models with an equal number of parameters. For a given category, this procedure may result in one or more retained models. Since Stages 1, 2, and 3 are purely statistical in nature; a retained model will have the best fit to the data for a particular category, but may yield implausible parameter estimates (e.g. a negative coefficient of external or internal influence). Stage 4 involves considering retained models which do not include implausible parameter estimates.

The number of categories studied prevents a concise reporting of all parameter estimates and tests.[4] Table 2 reports the frequency of models being retained after Stages 1, 2 and 3 are performed, as well as the frequency of "next best", yet plausible, models based on Stage 4. Table 3 and Table 4 summarize the values of parameters after the four stages were completed, while Figure 1 shows the fits of the best models to the data. A number of conclusions can be drawn from Table 2 with respect to diffusion model specifications, irrespective of parameter plausibility:

- no single specification is dominant in modeling the diffusion process for the nineteen consumer durables studied; a similar finding to Lavaraj and Gore (1990) who consider three consumer durables and three models.

- one category (5 percent of the total) is best modeled hybrid by a specification of the Fourt and Woodlock model which exhibits only innovative / external influences, a; seven categories (37 percent) exhibit pure imitation /internal influences, b, as originally modeled by Mansfield; eight categories (42 percent) exhibit mixed influences as specified in the Bass model; the three remaining categories (16 percent) are equally well via Mansfield or Bass-type diffusion processes; only two categories (10 percent) are best modeled using the five parameter diffusion model, equation (2), Model 1.

- the market potentials of seventeen categories (90 percent) require adjustment. Estimates of c_i are generally correlated with ultimate penetration levels reported in Table 3. Values greater than one for c_i can be explained, in part, by likely changes in category definition and the survey methodologies used over time (Kamakura and Balasubramanian (1988).

- all but two categories (90 percent) exhibit nonuniform interpersonal influences (NUI) 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 (1981).

- the number of parameters required to model the diffusion process varies across categories. The vast majority require either three of four parameters.

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

Two types of implausible parameter estimates are noteworthy.[5] First, for retained models which control for heterogeneous adopter populations, the value of e_i is often not plausible (e.g. $e_i<0$). Second, the value of external and internal coefficients are often extremely small with high standard errors. For example, the estimated best models for calculators and ironers are (significance levels in parentheses):

	Calculators		Ironers	
ai	2.039	(.14)	4.63E-10	(.82)
b_i	8.797	(.09)	3.19E-08	(.82)
c_i	0.988	(.00)	0.105	(.00)
d_i	-0.046	(.00)	3.807	(.00)
e_i	-0.282	(.00)	2.524	(.00)

Despite the high standard errors, eliminating either the a_i or b_i, may significantly reduce the fit of the model, as born out by likelihood ratio tests. Stage four involves eliminating parameters from such models in order to obtain plausible estimates. This procedure revealed that the two types of implausibilities are linked: in all cases where e_i is included in the model, the coefficients of external and internal influence are difficult to estimate. This can be understood by comparing the original Bass model's coefficients (equation 1) with those of the five parameter model (equation 2):

$$a_0 = a_i(c_iM(t) - F(t))^{e_i} \tag{9}$$

$$b_0 = b_i\,(c_iM(t) - F(t))^{e_i}\left(\frac{F(t)}{c_iM(t)}\right) \tag{10}$$

When e_i is included in the model, both external and internal coefficients are dynamic and assumed to be functions of highly collinear saturation terms. Multicollinearity present in mixed influence diffusion models, as noted by Heeler and Hustad (1980) and Schmittlein and Mahajan (1982) results in unstable values estimated with large standard errors for innovation and imitation coefficients (a_i, b_i) when both are estimated simultaneously. When only the internal influence coefficient is included in the model, the market saturation term is so large that its creates a strong downward scaling effect on b_i. As a general rule, the elimination of e_i yields plausible parameters estimates.

Empirical Guidelines

The two studies tend to reinforce each other and provide guidance on the appropriate choice of specific models:

- to adequately capture the long-run diffusion process, Bass-type diffusion models with at most four parameters will likely be sufficient (a_i, b_i, c_i and d_i); the best three parameter model assumes a_i to equal zero (or some small constant); the best two parameter model assumes that a_i=0 and d_i=0 (if c_i can be estimated externally, the best two parameter model assumes only that a_i=0); and the best one parameter model assumes that a_i=0, c_i=1, and d_i=0 (assuming M(t) is all wired households, estimated externally);

- controlling for heterogeneous adopter populations, via e_i, should be considered with the cautions made above;

- non-Bass parsimonious models will not provide greater explanatory power than parsimonious Bass models, and may perform substantially worse.

The remainder of this paper discusses the implications of these guidelines for the application of diffusion models in applied and academic research.

Implications

The most important contributions of diffusion models include (1) their ability to forecast both short-term sales, and long-run product life cycles, or household adoption processes, (2) their use to develop and test various theories relating to the consumer diffusion processes, and (3) their use in normative modeling efforts to derive optimal marketing strategies in new, or rapidly growing markets. The guidelines presented above have implications for each of the three activities.

Forecasting Implications

Research in new product forecasting using diffusion models has resulted in methods which are appropriate when there are few or no data available, including meta-analysis (Sultan, Farley and Lehmann 1990) and analogies across countries (Gatignon, Eliashberg, and Robertson 1989). As more observations become available, forecasts can be improved or model parameters updated via Bayesian estimation or feedback filters (Bretschneider and Mahajan 1980; Lenk and Rao 1990). Such techniques generally assume a unique diffusion process structure, or model; this is typically the basic mixed-influence Bass model. This paper would suggest that greater emphasis be placed on the flexible diffusion parameter d_i which captures relatively short, or extended take-off periods. While the number of categories studied in this paper is limited to consumer durables, our results and previous findings in the literature leads to a number of suggestions for estimating model parameters prior to launch when considering a model having four parameters (a_i, b_i, c_i, and d_i). Similar to decision calculus models which also have four parameters to capture sigmoid response functions (e.g. the CALLPLAN model, Lodish 1971), the best four parameter diffusion model can be characterized as having an intercept term (a_i), an ultimate penetration asymptote (c_i), and two shape parameters (b_i and d_i). Pre-launch forecasts require pre-launch estimates of these three types of parameters.

(1) The Intercept Parameter (a_i)

Forecasts of first year penetration generated from pre-launch purchase intention surveys (Juster 1966; Infosino 1988) can be used as an estimate of ai as this coefficient often acts as an intercept for first year penetration levels ($f(t)= a_iM(t)$ when $t=1$); as shown in Table 4, the average value of a_i is similar to the average value of the initial ($t=1$) penetration level (0.01), and the two values have a simple correlation of .52 (significant at .02 level). While a_i has relatively little impact on long-run diffusion, or the overall shape of the diffusion curve, this parameter does indicate the point at which the diffusion process starts. A high value of a_i leads to a quicker saturation than a low value of a_i. Lacking purchase intention information, assuming a_i to equal some small constant seems appropriate. For the categories studied, a_i averages .01 across all models. In a meta-analysis of 161 applications of the Bass model, Sultan, Farley and Lehmann find an average value of a_i to equal .03; this average does not consider, however, that some of the estimates of ai may not have been statistically different from zero.

(2) The Saturation Term (c_i)

The ultimate adoption level parameter, c_i, measures the long-run acceptance of the product among households and is significantly correlated with the maximum penetration level of the categories studied (.86). Methods to estimate c_i prior to launch might include basic research on market segmentation (e.g. perhaps only half of households, c_i=.5, in a particular region would ever need air-conditioning given the climate). In addition to intention surveys, survey research designed to measure future acquisition priorities may also provide reasonable pre-launch estimates of c_i (see, for example, Dickson, Lusch and Wilkies 1983; Clarke and Soutar 1982; Kasulis, Lusch and Stafford 1979; and Hauser and Urban 1986). As might be the case for ai, one might also use delphi or similar procedures using informed individuals to estimate c_i (Tigert and Farivar 1981).

(3) The Shape Parameters (b_i and d_i)

Attention should be placed on internal influences as captured by a constant base-line value, b_i, and a nonuniform influence parameter which makes such influences dynamic over the adoption process. Sultan, Farley and Lehmann find an average value of b_i to equal .38 (or .30 for durable goods) for the two parameter Bass model (equation 2). Our study indicates an average value of b_i to be 0.44. Though limited to nineteen categories, the summary statistics in Table 3 would indicate that b_i is a function of a_i and c_i, parameters which can be reasonably estimated prior to launch. The diffusion of categories with high external influence also have high internal influence levels, b_i. The higher the ultimate penetration level, however, the lower the value of b_i. In addition to using meta-analyses, one might wish to use pre-launch estimates of a_i and c_i to gauge b_i using the following estimated regression function (adjusted R-squared=.72; significance levels in parentheses).

$$\hat{b}_i = .6408 + 6.7890\, a_i - 0.4268\, c_i \qquad (11)$$

$$(.0001) \quad (.0002) \quad (.0025)$$

Of the four parameters, b_i is the most correlated with price, but this relationship is weak; higher prices are associated with higher levels in b_i. This finding is consistent with earlier research that has found price to affect the coefficient of internal influence more than the market potential (Jain and Rao; Kamakura and Balasubramanian). Higher priced products apparently prompt greater discussion/influence between early adopters and later adopters.

Estimating d_i prior to launch appears to be critical, yet problematic since models with the NUI parameter has seen less applications than models with the original Bass model parameters

(a_0 and b_0). One can not estimate d_i, however, independently of b_i. The positive correlation between b_i and d_i is .83 which is statistically significant (Table 3, footnote c). Referring to Table 4, the average value of the parameter in this study is 1.65; products with short take-off periods have negative values (e.g. black-and-white televisions. d_i=-.68), and those with longer take-off periods have values greater than zero (e.g. disposers, d_i=1.26). The correlation of .73 between the value of d_i and the number of years to the adoption curve peak is statistically significant. Qualls, Olshavsky and Michaels (1981) find that take-off periods are longest for consumer durables launched between 1922 and 1942, shorter for products launched between 1945 and 1964, and shortest for products launched between 1965 and 1979. Supporting the "shorter lifecycle" hypothesis, there is a significant negative correlation between d_i and the year of launch, -.60; recent products have faster diffusion and the lowest values of d_i (e.g. calculators d_i=-.25, water pulsators d_i=-.81, microwave ovens d_i=0), while the older products have the highest values of d_i (e.g. ranges d_i=5.11, vacuum cleaners d_i=6.78). The value of d_i from similar innovations having relatively recent histories might be considered for pre-launch estimates; a value likely to be less than zero and greater than minus 1 (e.g. -.8 for a "hot item" or a fad product; -.2 for a "typical", yet recent innovation; and 0 for a slow starter; 3.0 for an extremely slow starter). Fixing all other parameters, pre-launch estimates of d_i are, in effect, estimates of the number of years to the first purchase peak or the skew of the diffusion curve. Since b_i is a requisite coefficient of d_i, one can estimate a recursive model where the value of d_i is a function of the year of launch (e.g. launch=91 when the product is launched in 1991), and the estimated values of b_i from equation 11 (adjusted R-squared=.71; significance levels in parentheses):

$$\hat{d}_i = \underset{(.1019)}{1.5072} + \underset{(.0001)}{4.9066}\, \hat{b}_i - \underset{(.0007)}{0.0622}\ \text{launch} \tag{12}$$

Given the limited number of recent categories, and the possibility of implausible estimates $\left(\hat{d}_i < -1\right)$, more empirical research on factors affecting the level of d_i is warranted.

Once initial parameter estimates are obtained for a_i, b_i, c_i, and d_i (assuming a four parameter model), Sultan, Farley and Lehmann illustrate a Bayesian method which uses these estimates as priors for a category-level forecast. As new information (observations) becomes available (e.g. the first year penetration level), these priors can be updated to improve forecasting accuracy (Vanhonacker 1990; Vanhonacker, Lehmann and Sultan 1990).

Though our study is limited to nineteen categories, we can illustrate the implications of our findings in the context of forecasting a future consumer innovation: high definition television (HDTV), to be launched in the U.S. sometime between 1993 and 1997. As there are no data available on consumer adoption, a number of industry studies have forecasted HDTV sales by comparing the substitution rates between color and black-and-white televisions, and extrapolating these rates to projections of color television sales; adjustments have been made for economic and demographic growth. Figure 2 shows three forecasts made for HDTV sales for years following its commercial introduction: Darby (1988), Nathan Associates (1988) and Russel (1988). Each forecast assumes an initial period, about ten to fifteen years, during which first purchases will dominate sales, afterwhich replacement and multiple purchases will become substantial. The early years of these forecasts are fit well by the four parameter flexible diffusion model with certain parameter values. The forecast of Russel can be interpreted to deviate from the other forecasts based on its assumptions on the initial penetration level (a_i), the maximum penetration level (c_i) and the rate of diffusion (b_i, d_i); see Figure 2. Using the parameters which fit Russel's forecast as a bench mark, Figure 2 illustrates the impact of each parameter on the adoption process, while all others are held constant. As discussed above, a_i does not affect the overall shape of the adoption curve, but does affect the intercept, and, therefore, the years needed to reach the peak. The market potential parameter, c_i, does not affect the years to peak, but the absolute adoptions in any given year. The diffusion parameter b_i affects both the timing and amplitude of the peak, and the NUI parameter affects the skew or timing of the peak. Clearly, all four parameters play a critical role in modeling the adoption process and can, together, characterize a variety of diffusion patterns. Pre-launch forecasting should give attention to these parameters as relatively small variations in estimates can lead to rather dramatic differences in forecasts. Similarly, forecasts not based on diffusion models can be judged on their reasonableness by examining the diffusion parameters which are implicitly assumed.

Implications for Descriptive/Theoretical Research

The guidelines presented above stand to improve the relevance of marketing research by focussing greater attention on parameters which, to date, have received relatively little notice. In particular, this research suggests that long run diffusion is most explained by internal influences (reflected by values of b_i and d_i). Following Rogers belief that mass media affects early adopters most, previous studies have investigated whether the marketing mix affects innovation (a_i) or imitation coefficients (b_i) in the Bass model. Rogers notes that the earliest adopters are venturesome, product knowledgeable, and risk takers. Regardless of a firm's efforts, beyond minimal awareness and distribution campaigns, a small percent of the population is always likely to adopt the innovation (reflected in the small coefficient of external influence, a_i, which is often not statistically different from zero). An equally relevant focus is to ask which variables are most suited or likely to affect the coefficient of internal influence and the NUI parameter, as these have the greatest impact on the long-run diffusion process. In particular, efforts to make d_i (which can capture take-off length) a function of marketing-mix variables appears warranted. Likewise, variables likely to affect long-run acceptance (c_i), including cultural differences across countries, and product characteristics seems warranted; efforts in this direction include marking the market potential a function of price (Kalish 1985). While a number of studies have made the parameters of the basic diffusion model in equation 1 functions of product attributes (Horsky 1990), marketing mix variables (Horsky and Simon 1983, Simon and Sebastian 1987), and country-specific variables (Gatignon, Eliashberg and Robertson 1989), this research would suggest that similar efforts for the NUI parameter (d_i) and the ultimate penetration parameter (c_i) are warranted.

Normative Implications

Mahajan, Muller and Bass (p.21) call for empirical research which validates the relevance of models used in normative studies, as these are "simply working hypotheses". One surprising outcome of this research is that few, if any, of the specific functional forms considered in the normative literature are likely to best fit actual data for consumer durables; this is mainly due to the importance of c_i and d_i. This does not mean, however, that the prescriptions offered by normative researchers are incorrect as these are often derived based on formulations which generalize the four parameter model (Kalish 1983). What it does mean, however, is that efforts to implement normative models as an applied tool will need to consider modifying functional forms which better meet the guidelines presented above. For example, some attention has previously been placed on deriving and evaluating pricing strategies when a_i is greater than b_i (external influences are dominant), or vice versa. This study would suggest that efforts be made to determine optimal strategies when c_i or d_i are low, or high, or a function of various marketing mix elements. Further empirical research in this area will likely provide insights into appropriate modelling frameworks. Because models with d_i expressed as differential equations cannot be solved in closed-form, normative prescriptions will likely rely on numerical simulations, hence a greater need for empirical research concerning c_i and d_i, such as the meta-analysis conducted by Sultan, Farley and Lehmann who consider a_i and b_i.

Other Issues

The comparison of alternative diffusion specifications indicates that the Bass model, and its recent modifications, form a sound basis for modeling diffusion processes. Mahajan, Muller and Bass (p.21) note the need "to identify conditions under which diffusion models work or do not work". Our research would suggest that models which do not consider external influences (b_i), ultimate adopter ceilings (c_i) and non-uniform interpersonal influences (d_i) do not generally work well in explaining the diffusion process. The normal caveats apply, however, to the guidelines presented above in that only nineteen categories within the same industry were studied without the consideration of other variables (e.g. marketing mix variables).[6] Also, with the exception of ironers, only categories which have attained a certain level of success were studied. Considering products which have failed would be a useful extension of this study.

Another concern is that we have limited ourselves to considering fit statistics as a measure of each model's explanatory power; we do not evaluate the various models on their forecasting capabilities. Often there is reason to believe that the best fitting long-run model will provide the best long-run forecasts (if parameters can be accurately calibrated). This appears to be the case for the models studied here. Research conducted by Rao (1985) compares the forecasting accuracy of six diffusion models and five trend extrapolation models using four consumer durable categories. That study supports our findings in that among the diffusion models studied, "the NUI model [which includes a_i, b_i and di] seems to be the best forecasting tool (p. 240)"; the study did not consider models with the long-run market potential adjustment parameter, $c_i<1$.

While forecasting is one aspect of diffusion models, the variety of models which appear to best explain the diffusion process leads to a number of questions. On an a-priori basis, do qualitative aspects of the products or the social system result in one specification being more appropriate than another? This research would suggest that all diffusion processes can be adequately modeled by four parameters; more parsimonious models should be nested specifications of the general model (Model 2). Future research evaluating the sensitivity of our results to different industries, social systems, or situations will allow more general conclusions in this regard.

FOOTNOTES

1. Of the ten types of models reported in Mahajan, Muller and Bass (1990), this paper considers all but two: the FLOG, or flexible logistic model (Bewley and Fiebig 1988) and the Sharif and Kabir (1976) model. The models considered in this study all have a comparable coefficient of internal influence.

2. All models were estimated using nonlinear least squares, yet some models resulted in biased parameter estimates due to multicollinearity, or failed to converge. Tests, including dummy variables or using alternative meta-analyses eliminating these observations, indicated that our results are insensitive to these estimation issues. When such affects are statistically significant, dummy variables are included in the ANOVA models.

3. Rather than specific category dummy variables, alternative variables controlling for the number of observations for each category, the number of years between the product launch and the adoption peak, and the price (min, max, and average), adjusted for inflation and/or income were considered. The use of these alternative variables do not change the overall conclusions of the ANOVA.

4. A more complete reporting of the estimates is available from the author.

5. Values of $b_i > 1$ are plausible given that they occur for values of $d_i > 0$.

6. In separate studies which include price (Kamakura and Balasubramanian; Jain and Rao), similar functional forms are found best among the alternatives (excluding d_i).

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

Table 2. Summary of Study Results

					Study # 1		Study # 2	
Model	Parameters Included	Number of Parameters	Number of parameters c_i given	Mean r	ANOVA models by number of parameters[a]	ANOVA results	Frequency of being "Best Model"	Frequency of being "Best", or next best and plausible
1	a b c d e	5	4	.867	-	-	2	0
2	a b c d	4	3	.864	.96 (.00)	[n = 76	5	7
3	b c d e	4	3	.84	-.01 (.53)	R_a^2 = .79	3	0
4	a b c e	4	3	.78	-.04 (.03)	F= 14.1 (.00)	1	0
5	a b d e	4	-	.75	-.09 (.00)	SSE= .18]	0	0
6	b c d	3	2	.81	.85 (.00)		4	6
7	b c e	3	2	.78	-.05 (.12)		1	0
8	a b c	3	2	.76	-.04 (.25)		0	0
9	b d e	3	-	.74	-.09 (.00)	[n = 133	0	0
10	a b d	3	-	.72	-.11 (.00)	R_a^2 = .76	1	2
11	a b e	3	-	.72	-.08 (.01)	F =16.2 (.00)	0	0
12	a c e	3	2	.46	-.19 (.00)	SSE = .92]	1	0
13	b c	2	1	.74	.47 (.00)		0	0
NELDER	b g	2	-	.74	-.00 (.95)		-	-
14	a b	2	-	.68	-.08 (.17)		0	1
15	b d	2	-	.67	-.09 (.10)	[n = 133	1	2
16	b e	2	-	.66	-.10 (.08)	R_a^2 =.72	0	0
17	a c	2	1	.55	-.18 (.00)	F = 15.3 (.00)	0	0
18	a e	2	-	.33	-.43 (.00)	SSE = 1.08]	0	0
19	b	1	-	.59	.77 (.00)		1	1
FLOYD	b	1	-	.59	-.01 (.87)	[n = 95	-	-
SRI	b	1	-	.49	-.13 (.15)	R_a^2 = .65	-	-
GOMPERZ	b	1	-	.48	-.14 (.15)	F = 9.0 (.00)	-	-
20	a	1	-	.13	-.47 (.00)	SSE = 5.11]	0	0

a. the ANOVA models included 18 category dummy variables, and significant estimation dummies (see footnote 2); significance levels in parentheses; ".00" signifies a values less than .01.

Table 3. Summary of Best and Plausible Parameter Estimates[a].

	a_i	b_i	c_i	d_i
Minimum	.0000	.0511	.0927	-.8100
Maximum	.0915	1.1800	1.2734	10.6010
Mean	.0221	.4424	.7868	1.6494
Standard Deviation	.0294	.3349	.3466	3.0151
Correlation				
a_i	1	-	-	-
b_i	.7324 (.00)	1	-	-
c_i	-.2877 (.21)	-.6369 (.00)	1	-
d_i	.4596[b] (.04)	.4068[c] (.07)	-.1825 (.42)	1
Launch Year	-.1800 (.43)	-.3716 (.10)	.0156 (.95)	-.4601[d] (.04)
Year to Peak	.1985 (.39)	.3986 (.07)	-.1226 (.60)	.6441[e] (.00)
Initial Penetration	.5210 (.02)	.1886 (.41)	.2440 (.29)	.3153 (.16)
Maximum Penetration	.0767 (.74)	-.3907 (.08)	.8551 (.00)	-.2779 (.43)
Minimum Price	.2533 (.27)	.3922 (.08)	-.2570 (.26)	.3852 (.08)
Maximum Price	-.0152 (.95)	.2642 (.24)	-.0664 (.77)	.2378 (.30)
Average Price	-.0793 (.73)	.2087 (.36)	-.0138 (.95)	.1800 (.43)

Note:
a. significance levels in parentheses; ".00" signifies a value less than .01.
b. correlation equals .6838 (.00) when freezers are excluded; the late growth of freezers coincides with the launch of microwave ovens (ie the diffusion of a complimentary product).
c. correlation equals .8338 (.00) when freezers are excluded.
d. correlation equals -.6027 (.00) when freezers are excluded.
e. correlation equals .7317 (.00) when freezers are excluded.

Table 4. Summary of Best and Plausible Parameter Estimates by Category Characteristics[a].

Categories sorted by b_i	a_i	b_i	Initial $\left[\frac{F(t)}{M(t)}\right]$	Categories sorted by c_i	c_i	Maximum $\left[\frac{F(t)}{M(t)}\right]$	Categories sorted by d_i	d_i	Years to Peak	Years Studied
Freezers	0.01	0.05	0.01	Ironers	0.09	0.09	Pulsators	-0.81	3	1966-1979
Bed Covers	0.00	0.10	0.02	Pulsators	0.18	0.15	TV: B & W	-0.68	6	1948-1979
Bed Covers	0.01	0.10	0.02	Built-in-Range	0.20	0.20	Steam Irons	-0.59	18	1949-1979
Steam Irons	0.00	0.11	0.04	Disposers	0.44	0.43	TV: Color	-0.50	13	1960-1986
Pulsators	0.00	0.20	0.01	Dishwashers	0.47	0.43	TV: Color	-0.42	13	1960-1986
TV: Color	0.00	0.21	0.00	Ranges (el.)	0.52	0.52	Bed Covers	-0.35	19	1948-1979
TV: Color	0.00	0.27	0.01	Room A/C	0.58	0.56	Calculators	-0.25	4	1972-1987
TV: B & W	0.00	0.27	0.01	Dryers	0.64	0.62	Microwaves	0.00	15	1971-1987
Blenders	0.00	0.30	0.01	Washers	1.00	0.96	Refrigerators	0.00	21	1925-1979
Dishwashers	0.00	0.35	0.00	TV: Color	1.00	0.91	Bed Covers	0.00	31	1948-1979
Refrigerators	0.00	0.38	0.00	Blenders	1.00	0.52	Dishwashers	0.29	24	1948-1979
Microwaves	0.00	0.39	0.00	Bed Covers	1.00	0.64	Blenders	0.57	21	1949-1979
Washers	0.05	0.41	0.25	Microwaves	1.00	0.59	Room A/C	0.97	23	1949-1979
Room A/C	0.02	0.45	0.01	Freezers	1.00	0.45	Dryers	1.22	23	1948-1979
Dryers	0.02	0.45	0.00	Bed Covers	1.00	0.64	Disposers	1.26	26	1948-1979
Calculators	0.09	0.56	0.09	Calculators	1.01	0.97	Washers	2.12	17	1926-1961
Disposers	0.02	0.62	0.00	Vacuums	1.01	0.99	Ironers	3.28	16	1927-1954
Vacuums	0.06	0.75	0.32	TV: Color	1.02	0.91	Ranges (el.)	5.11	44	1925-1977
Ranges (el.)	0.04	1.01	0.03	Refrigerators	1.05	0.99	Vacuums	6.78	40	1923-1979
Ironers	0.06	1.16	0.02	TV: B & W	1.05	0.99	Built-in-Range	5.74	19	1956-1978
Built-in-Range	0.08	1.18	0.01	Steam Irons	1.27	0.99	Freezers	10.60	27	1948-1978
Mean	0.014[b]	0.44	0.018[b]	Means	0.79	0.64	Means	1.65	19.4	-

a. parameter estimates greater than zero are statistically significant ($p < .00$). Otherwise, when parameter values were not included in the final models, $a_i = 0$, $c_i = 1$ and $d_i = 0$.

a. Mean values exclude Washers and Vacuums, as initial penetrations reflect lags in reporting the category after launch; "0.00" signifies a level less than .01.

Figure 1. Adoption Data (f(t)) and Fitted Values from Best Models ($\hat{f}(t)$), by category over time.

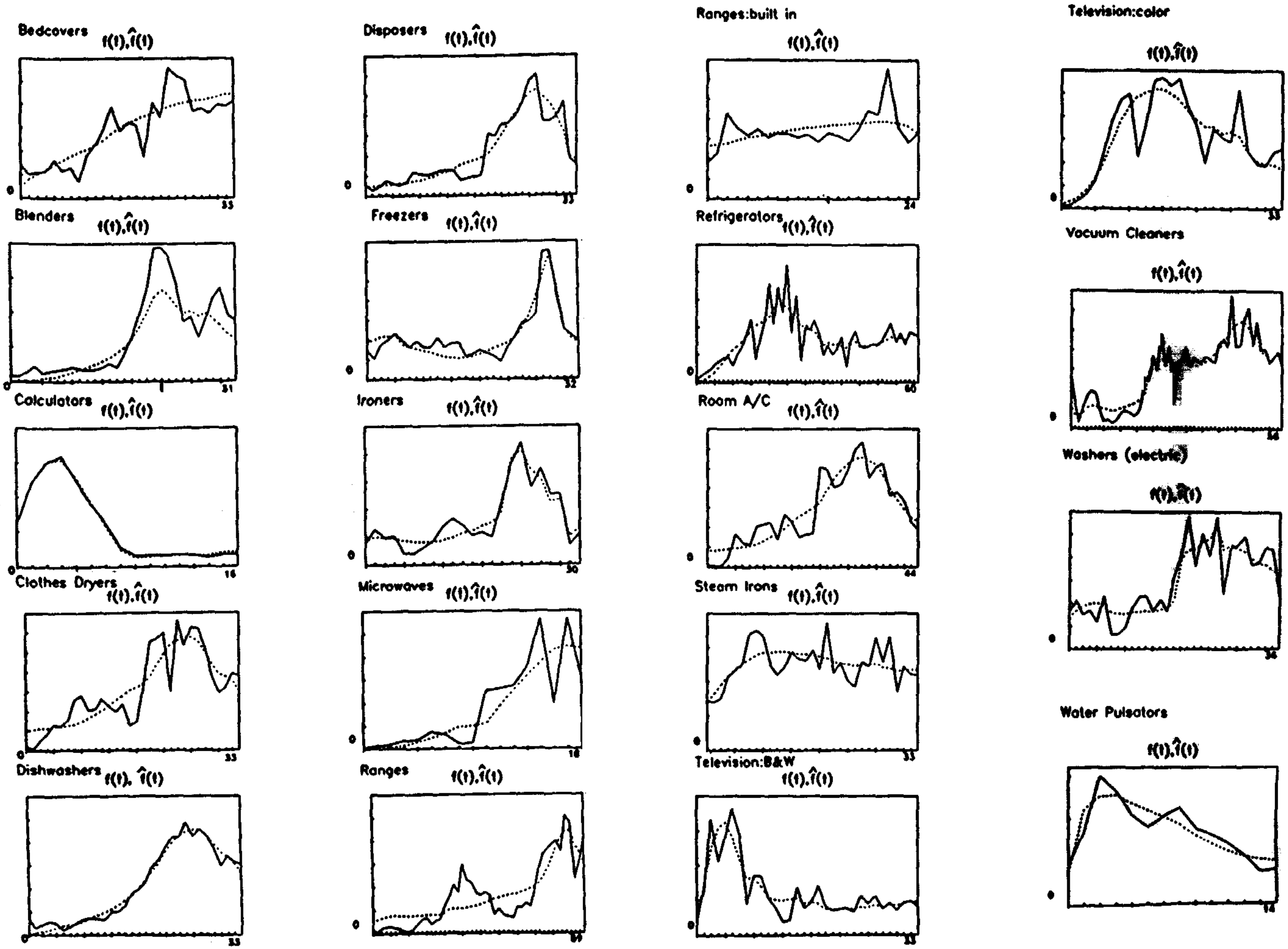
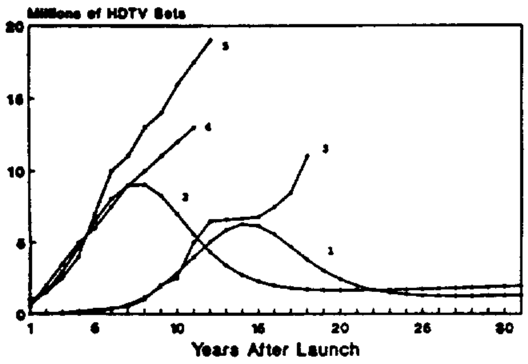
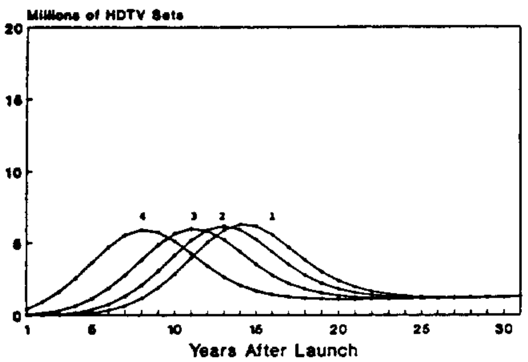


Figure 2. HDTV Forecasts and Diffusion Sensitivities;M(t) is extrapolated from 1993 on.



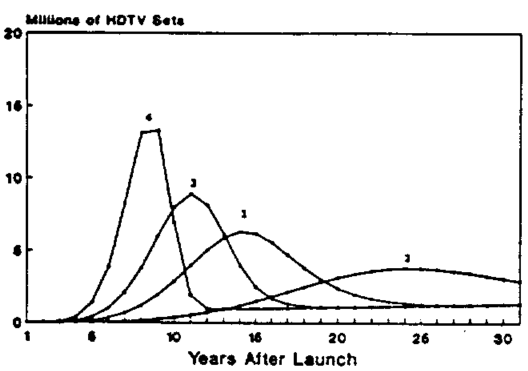
Legend

1.	$a_i = .00001$	$b_i = .4$	$c_i = .4$	$d_i = -.25$
2.	$a_i = .01$	$b_i = .4$	$c_i = .6$	$d_i = -.30$
3.	Russel (1988)			
4.	Nathan Associates (1988)			
5.	Darby (1988)			



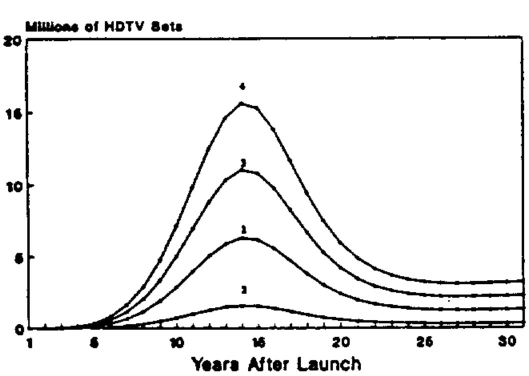
a_i varies

1.	$a_i = .00001$	$b_i = .4$	$c_i = .4$	$d_i = -.25$
2.	$a_i = .0001$	$b_i = .4$	$c_i = .4$	$d_i = -.25$
3.	$a_i = .001$	$b_i = .4$	$c_i = .4$	$d_i = -.25$
4.	$a_i = .01$	$b_i = .4$	$c_i = .4$	$d_i = -.25$



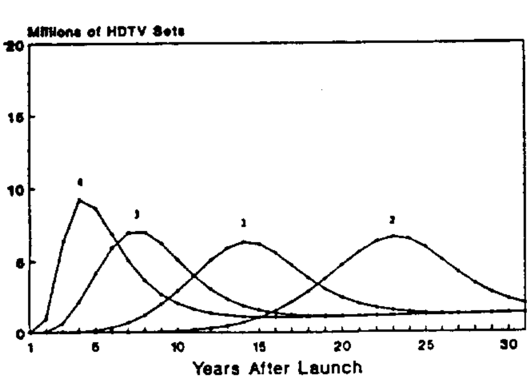
b_i varies

1.	$a_i = .00001$	$b_i = .4$	$c_i = .4$	$d_i = -.25$
2.	$a_i = .00001$	$b_i = .2$	$c_i = .4$	$d_i = -.25$
3.	$a_i = .00001$	$b_i = .6$	$c_i = .4$	$d_i = -.25$
4.	$a_i = .00001$	$b_i = .99$	$c_i = .4$	$d_i = -.25$



c_i varies

1.	$a_i = .00001$	$b_i = .4$	$c_i = .4$	$d_i = -.25$
2.	$a_i = .00001$	$b_i = .4$	$c_i = .1$	$d_i = -.25$
3.	$a_i = .00001$	$b_i = .4$	$c_i = .7$	$d_i = -.25$
4.	$a_i = .00001$	$b_i = .4$	$c_i = .99$	$d_i = -.25$



d_i varies

1.	$a_i = .00001$	$b_i = .4$	$c_i = .4$	$d_i = -.25$
2.	$a_i = .00001$	$b_i = .4$	$c_i = .4$	$d_i = -.10$
3.	$a_i = .00001$	$b_i = .4$	$c_i = .4$	$d_i = -.50$
4.	$a_i = .00001$	$b_i = .4$	$c_i = .4$	$d_i = -.75$

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90/26 OB/BP	Charles KADUSHIN and Michael BRIMM	**"Why networking Fails: Double Binds and the Limitations of Shadow Networks"**, February 1990.
90/27 TM	Abbas FOROUGHI and Tawfik JELASSI	**"NSS Solutions to Major Negotiation Stumbling Blocks"**, February 1990.
90/28 TM	Arnoud DE MEYER	**"The Manufacturing Contribution to Innovation"**, February 1990.

90/29 FIN/AC	Nathalie DIERKENS	"A Discussion of Correct Measures of Information Asymmetry", January 1990.
90/30 FIN/EP	Lars Tyge NIELSEN	"The Expected Utility of Portfolios of Assets", March 1990.
90/31 MKT/EP	David GAUTSCHI and Roger BETANCOURT	"What Determines U.S. Retail Margins?", February 1990.
90/32 SM	Srinivasan BALAK- RISHNAN and Mitchell KOZA	"Information Asymmetry, Adverse Selection and Joint-Ventures: Theory and Evidence", Revised, January 1990.
90/33 OB	Caren SIEHL, David BOWEN and Christine PEARSON	"The Role of Rites of Integration in Service Delivery", March 1990.
90/34 FIN/EP	Jean DERMINE	"The Gains from European Banking Integration, a Call for a Pro-Active Competition Policy", April 1990.
90/35 EP	Jae Won PARK	"Changing Uncertainty and the Time-Varying Risk Premia in the Term Structure of Nominal Interest Rates", December 1988, Revised March 1990.
90/36 TM	Arnoud DE MEYER	"An Empirical Investigation of Manufacturing Strategies in European Industry", April 1990.
90/37 TM/OB/SM	William CATS-BARIL	"Executive Information Systems: Developing an Approach to Open the Possibles", April 1990.
90/38 MKT	Wilfried VANHONACKER	"Managerial Decision Behaviour and the Estimation of Dynamic Sales Response Models", (Revised February 1990).
90/39 TM	Louis LE BLANC and Tawfik JELASSI	"An Evaluation and Selection Methodology for Expert System Shells", May 1990.
90/40 OB	Manfred KETS DE VRIES	"Leaders on the Couch: The case of Roberto Calvi", April 1990.
90/41 FIN/EP	Gabriel HAWAWINI, Itzhak SWARY and Ik HWAN JANG	"Capital Market Reaction to the Announcement of Interstate Banking Legislation", March 1990.
90/42 MKT	Joel STECKEL and Wilfried VANHONACKER	"Cross-Validating Regression Models in Marketing Research", (Revised April 1990).
90/43 FIN	Robert KORAJCZYK and Claude VIALLET	"Equity Risk Premia and the Pricing of Foreign Exchange Risk", May 1990.
90/44 OB	Gilles AMADO, Claude FAUCHEUX and André LAURENT	"Organisational Change and Cultural Realities: Franco-American Contrasts", April 1990.
90/45 TM	Soumitra DUTTA and Piero BONISSONE	"Integrating Case Based and Rule Based Reasoning: The Possibilistic Connection", May 1990.
90/46 TM	Spyros MAKRIDAKIS and Michèle HIBON	"Exponential Smoothing: The Effect of Initial Values and Loss Functions on Post-Sample Forecasting Accuracy".
90/47 MKT	Lydia PRICE and Wilfried VANHONACKER	"Improper Sampling in Natural Experiments: Limitations on the Use of Meta-Analysis Results in Bayesian Updating", Revised May 1990.
90/48 EP	Jae WON PARK	"The Information in the Term Structure of Interest Rates: Out-of-Sample Forecasting Performance", June 1990.
90/49 TM	Soumitra DUTTA	"Approximate Reasoning by Analogy to Answer Null Queries", June 1990.
90/50 EP	Daniel COHEN and Charles WYPLOSZ	"Price and Trade Effects of Exchange Rates Fluctuations and the Design of Policy Coordination", April 1990.

90/51 EP	Michael BURDA and Charles WYPLOSZ	"Gross Labour Market Flows in Europe: Some Stylized Facts", June 1990.
90/52 FIN	Lars Tyge NIELSEN	"The Utility of Infinite Menus", June 1990.
90/53 EP	Michael Burda	"The Consequences of German Economic and Monetary Union", June 1990.
90/54 EP	Damien NEVEN and Colin MEYER	"European Financial Regulation: A Framework for Policy Analysis", (Revised May 1990).
90/55 EP	Michael BURDA and Stefan GERLACH	"Intertemporal Prices and the US Trade Balance", (Revised July 1990).
90/56 EP	Damien NEVEN and Lars-Hendrik RÖLLER	"The Structure and Determinants of East-West Trade: A Preliminary Analysis of the Manufacturing Sector", July 1990
90/57 FIN/EP/ TM	Lars Tyge NIELSEN	Common Knowledge of a Multivariate Aggregate Statistic", July 1990
90/58 FIN/EP/TM	Lars Tyge NIELSEN	"Common Knowledge of Price and Expected Cost in an Oligopolistic Market", August 1990
90/59 FIN	Jean DERMINE and Lars-Hendrik RÖLLER	"Economies of Scale and Scope in the French Mutual Funds (SICAV) Industry", August 1990
90/60 TM	Peri IZ and Tawfik JELASSI	"An Interactive Group Decision Aid for Multiobjective Problems: An Empirical Assessment", September 1990
90/61 TM	Pankaj CHANDRA and Mihkel TOMBAK	"Models for the Evlauation of Manufacturing Flexibility", August 1990
90/62 EP	Damien NEVEN and Menno VAN DIJK	"Public Policy Towards TV Broadcasting in the Netherlands", August 1990
90/63 SM	Sumantra GHOSHAL and Eleanor WESTNEY	"Organising Competitor Analysis Systems", August 1990
90/64 SM	Sumantra GHOSHAL	"Internal Differentiation and Corporate Performance: Case of the Multinational Corporation", August 1990
90/65 EP	Charles WYPLOSZ	"A Note on the Real Exchange Rate Effect of German Unification", August 1990
90/66 TM/SE/FIN	Soumitra DUTTA and Piero BONISSONE	"Computer Support for Strategic and Tactical Planning in Mergers and Acquisitions", September 1990
90/67 TM/SE/FIN	Soumitra DUTTA and Piero BONISSONE	"Integrating Prior Cases and Expert Knowledge In a Mergers and Acquisitions Reasoning System", September 1990
90/68 TM/SE	Soumitra DUTTA	"A Framework and Methodology for Enhancing the Business Impact of Artificial Intelligence Applications", September 1990
90/69 TM	Soumitra DUTTA	"A Model for Temporal Reasoning in Medical Expert Systems", September 1990
90/70 TM	Albert ANGEHRN	"'Triple C': A Visual Interactive MCDSS", September 1990
90/71 MKT	Philip PARKER and Hubert GATIGNON	"Competitive Effects in Diffusion Models: An Empirical Analysis", September 1990
90/72 TM	Enver YÜCESAN	"Analysis of Markov Chains Using Simulation Graph Models", October 1990
90/73 TM	Arnoud DE MEYER and Kasra FERDOWS	"Removing the Barriers in Manufacturing", October 1990
90/74 SM	Sumantra GHOSHAL and Nitin NOHRIA	"Requisite Complexity: Organising Headquarters-Subsidiary Relations in MNCs", October 1990

90/75 MKT	Roger BETANCOURT and David GAUTSCHI	"The Outputs of Retail Activities: Concepts, Measurement and Evidence", October 1990
90/76 MKT	Wilfried VANHONACKER	"Managerial Decision Behaviour and the Estimation of Dynamic Sales Response Models", Revised October 1990
90/77 MKT	Wilfried VANHONACKER	"Testing the Koyck Scheme of Sales Response to Advertising: An Aggregation-Independent Autocorrelation Test", October 1990
90/78 EP	Michael BURDA and Stefan GERLACH	"Exchange Rate Dynamics and Currency Unification: The Ostmark - DM Rate", October 1990
90/79 TM	Anil GABA	"Inferences with an Unknown Noise Level in a Bernoulli Process", October 1990
90/80 TM	Anil GABA and Robert WINKLER	"Using Survey Data in Inferences about Purchase Behaviour", October 1990
90/81 TM	Tawfik JELASSI	"Du Présent au Futur: Bilan et Orientations des Systèmes Interactifs d'Aide à la Décision," October 1990
90/82 EP	Charles WYPLOSZ	"Monetary Union and Fiscal Policy Discipline," November 1990
90/83 FIN/TM	Nathalie DIERKENS and Bernard SINCLAIR-DESGAGNE	"Information Asymmetry and Corporate Communication: Results of a Pilot Study", November 1990
90/84 MKT	Philip M. PARKER	"The Effect of Advertising on Price and Quality: The Optometric Industry Revisited," December 1990
90/85 MKT	Avijit GHOSH and Vikas TIBREWALA	"Optimal Timing and Location in Competitive Markets," November 1990
90/86 EP/TM	Olivier CADOT and Bernard SINCLAIR-DESGAGNE	"Prudence and Success in Politics," November 1990
90/87 FIN/EP	Lars Tyge NIELSEN	"Existence of Equilibrium in CAPM: Further Results", December 1990
90/88 OB/MKT	Susan C. SCHNEIDER and Reinhard ANGELMAR	"Cognition in Organisational Analysis: Who's Minding the Store?" Revised, December 1990
90/89 OB	Manfred F.R. KETS DE VRIES	"The CEO Who Couldn't Talk Straight and Other Tales from the Board Room," December 1990
90/90 MKT	Philip PARKER	"Price Elasticity Dynamics over the Adoption Lifecycle: An Empirical Study," December 1990

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91/01 TM/SM	Luk VAN WASSENHOVE, Leonard FORTUIN and Paul VAN BEEK	"Operational Research Can Do More for Managers Than They Think!," January 1991
91/02 TM/SM	Luk VAN WASSENHOVE, Leonard FORTUIN and Paul VAN BEEK	"Operational Research and Environment," January 1991
91/03 FIN	Pekka HIETALA and Timo LÖYTTYNIEMI	"An Implicit Dividend Increase in Rights Issues: Theory and Evidence," January 1991
91/04 FIN	Lars Tyge NIELSEN	"Two-Fund Separation, Factor Structure and Robustness," January 1991
91/05 OB	Susan SCHNEIDER	"Managing Boundaries in Organisations," January 1991
91/06 OB	Manfred KETS DE VRIES, Danny MILLER and Alain NOEL	"Understanding the Leader-Strategy Interface: Application of the Strategic Relationship Interview Method," January 1990 (89/11, revised April 1990)

91/07 EP	Olivier CADOT	"Lending to Insolvent Countries: A Paradoxical Story," January 1991
91/08 EP	Charles WYPLOSZ	"Post-Reform East and West: Capital Accumulation and the Labour Mobility Constraint," January 1991
91/09 TM	Spyros MAKRIDAKIS	"What can we Learn from Failure?", February 1991
91/10 TM	Luc Van WASSENHOVE and C. N. POTTS	"Integrating Scheduling with Batching and Lot-Sizing: A Review of Algorithms and Complexity", February 1991
91/11 TM	Luc VAN WASSENHOVE et al.	"Multi-Item Lotsizing in Capacitated Multi-Stage Serial Systems", February 1991
91/12 TM	Albert ANGEHRN	"Interpretative Computer Intelligence: A Link between Users, Models and Methods in DSS", February 1991
91/13 EP	Michael BURDA	"Labor and Product Markets in Czechoslovakia and the Ex-GDR: A Twin Study", February 1991
91/14 MKT	Roger BETANCOURT and David GAUTSCHI	"The Output of Retail Activities: French Evidence", February 1991
91/15 OB	Manfred F.R. KETS DE VRIES	"Exploding the Myth about Rational Organisations and Executives", March 1991
91/16 TM	Arnoud DE MEYER and Kasra FERDOWS et.al.	"Factories of the Future: Executive Summary of the 1990 International Manufacturing Futures Survey", March 1991
91/17 TM	Dirk CATTRYSSE, Roelof KUIK, Marc SALOMON and Luk VAN WASSENHOVE	"Heuristics for the Discrete Lotsizing and Scheduling Problem with Setup Times", March 1991
91/18 TM	C.N. POTTS and Luk VAN WASSENHOVE	"Approximation Algorithms for Scheduling a Single Machine to Minimize Total Late Work", March 1991
91/19 MKT	Vikas TIBREWALA and Bruce BUCHANAN	"An Aggregate Test of Purchase Regularity", March 1991
91/20 MKT	Darius SABAVALA and Vikas TIBREWALA	"Monitoring Short-Run Changes in Purchasing Behaviour", March 1991
91/21 SM	Sumantra GHOSHAL, Harry KORINE and Gabriel SZULANSKI	"Interunit Communication within MNCs: The Influence of Formal Structure Versus Integrative Processes", April 1991
91/22 EP	David GOOD, Lars-Hendrik RÖLLER and Robin SICKLES	"EC Integration and the Structure of the Franco-American Airline Industries: Implications for Efficiency and Welfare", April 1991
91/23 TM	Spyros MAKRIDAKIS and Michèle HIBON	"Exponential Smoothing: The Effect of Initial Values and Loss Functions on Post-Sample Forecasting Accuracy", April 1991 (Revision of 90/46)
91/24 TM	Louis LE BLANC and Tawfik JELASSI	"An Empirical Assessment of Choice Models for Software Evaluation and Selection", May 1991
91/25 SM/TM	Luk N. VAN WASSENHOVE and Charles J. CORBETT	"Trade-Offs? What Trade-Offs?" April 1991

91/07 EP	Olivier CADOT	"Lending to Insolvent Countries: A Paradoxical Story," January 1991
91/08 EP	Charles WYPLOSZ	"Post-Reform East and West: Capital Accumulation and the Labour Mobility Constraint," January 1991
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91/24 TM	Louis LE BLANC and Tawfik JELASSI	"An Empirical Assessment of Choice Models for Software Evaluation and Selection", May 1991
91/25 SM/TM	Luk N. VAN WASSENHOVE and Charles J. CORBETT	"Trade-Offs? What Trade-Offs?" April 1991
91/26 TM	Luk N. VAN WASSENHOVE and C.N. POTTS	"Single Machine Scheduling to Minimize Total Late Work", April 1991
91/27 FIN	Nathalie DIERKENS	"A Discussion of Correct Measures of Information Asymmetry: The Example of Myers and Majluf's Model or the Importance of the Asset Structure of the Firm", May 1991
91/28 MKT	Philip M. PARKER	"A Note on: 'Advertising and the Price and Quality of Optometric Services', June 1991
91/29 TM	Tawfik JELASSI and Abbas FOROUGHI	"An Empirical Study of an Interactive, Session-Oriented Computerised Negotiation Support System (NSS)", June 1991

91/30 MKT	Wilfried R. VANHONACKER and Lydia J. PRICE	**"Using Meta-Analysis Results in Bayesian Updating: The Empty Cell Problem"**, June 1991
91/31 FIN	Rezaul KABIR and Theo VERMAELEN	**"Insider Trading Restrictions and the Stock Market"**, June 1991
91/32 OB	Susan C. SCHNEIDER	**"Organisational Sensemaking: 1992"**, June 1991
91/33 EP	Michael C. BURDA and Michael FUNKE	**"German Trade Unions after Unification - Third Degree Wage Discriminating Monopolists?"**, June 1991
91/34 FIN	Jean DERMINE	**"The BIS Proposal for the Measurement of Interest Rate Risk, Some Pitfalls"**, June 1991
91/35 FIN	Jean DERMINE	**"The Regulation of Financial Services in the EC, Centralization or National Autonomy?"** June 1991
91/36 TM	Albert ANGEHRN	**"Supporting Multicriteria Decision Making: New Perspectives and New Systems"**, August 1991
91/37 EP	Ingo WALTER and Hugh THOMAS	**"The Introduction of Universal Banking in Canada: An Event Study"**, August 1991
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91/40 TM	Luk VAN WASSENHOVE, Dirk CATTRYSSE and Marc SALOMON	**"A Set Partitioning Heuristic for the Generalized Assignment Problem"**, August 1991
91/41 TM	Luk VAN WASSENHOVE, M.Y. KOVALYOU and C.N. POTTS	**"A Fully Polynomial Approximation Scheme for Scheduling a Single Machine to Minimize Total Weighted Late Work"**, August 1991
91/42 TM	Rob R. WEITZ and Tawfik JELASSI	**"Solving A Multi-Criteria Allocation Problem: A Decision Support System Approach"**, August 1991
91/43 SM	Sumantra GHOSHAL and Christopher BARTLETT	**"Building Transnational Capabilities: The Management Challenge"**, September 1991
91/44 SM	Sumantra GHOSHAL and Nitin NOHRIA	**"Distributed Innovation in the 'Differentiated Network' Multinational"**, September 1991
91/45 MKT	Philip M. PARKER	**"The Effect of Advertising on Price and Quality: An Empirical Study of Eye Examinations, Sweet Lemons and Self-Deceivers"**, September 1991
91/46 MKT	Philip M. PARKER	**"Pricing Strategies in Markets with Dynamic Elasticities"**, October 1991
91/47 MKT	Philip M. PARKER	**"A Study of Price Elasticity Dynamics Using Parsimonious Replacement/Multiple Purchase Diffusion Models"**, October 1991
91/48 EP/TM	H. Landis GABEL and Bernard SINCLAIR-DESGAGNE	**"Managerial Incentives and Environmental Compliance"**, October 1991
91/49 TM	Bernard SINCLAIR-DESGAGNE	**"The First-Order Approach to Multi-Task Principal-Agent Problems"**, October 1991
91/50 SM/TM	Luk VAN WASSENHOVE and Charles CORBETT	**"How Green is Your Manufacturing Strategy?"** October 1991