JOURNAL OF MEDIA ECONOMICS, *18*(4), 233–246

Toward an Economic Theory of Media Diffusion Based on the Parameters of the Logistic Growth Equation

John Dimmick and Tao Wang
School of Communication
The Ohio State University

This article suggests that the logistic growth equation is the model underlying media diffusion. The logistic is shown to be a good fit to the diffusion of U.S. communication media such as radio, TV, cable, VCR, and the home computer. This article proposes that the *r* and *K* parameters of the logistic can be interpreted, respectively, as anticipated gratification utilities and economic conditions. In addition, the results of hypothesis testing showed that step variables representing changes in anticipated gratification utilities were related to the diffusion of cable and the personal computer. A hypothesis predicting a relation between disposable income and diffusion of U.S. communication media was supported only for the personal computer. We believe further research should attempt to measure variables representing *r* and *K* at the individual or household level.

The acceptance of a new medium into a society, as traced by its diffusion, has profound economic consequences. To adopt a new medium, consumers may have to spend money both to acquire the necessary durable good (e.g., a TV set or computer) as well as for the requisite service (e.g., a cable subscription or Internet connection). Once adopted by a substantial segment of consumers, the new medium, such as cable or the Internet, may become a vehicle of commerce purveying advertising messages. Not surprisingly, then, research on media adoption (e.g., Atkin, Neuendorf, Jeffres, & Skalski, 2003; Dupagne, 1999) sometimes appears in the media economics and management literature.

The purpose of this article is to build on the diffusion literature in the social sciences and media economics and management literature to produce the beginnings

Correspondence should be addressed to John Dimmick, School of Communication, The Ohio State University, 3016 Derby Hall, 154 N. Oval Mall, Columbus, OH 43210. E-mail: dimmick.1@osu.edu

of a theory of media diffusion that is more strongly rooted in economics than the traditional media diffusion studies as exemplified in the classic work of Rogers (1995). The theory development and hypothesis-testing reported in this article were stimulated by consideration of the parameters of a venerable equation used in other fields to represent diffusion, the logistic growth equation.

It is commonplace in the contemporary world to say that there are no renaissance men (or renaissance women either) because of the enormous complexity and bewildering disparity of scientific disciplines, fields, and subfields. Such clichés, however, easily glide over the reality that there are a number of constructs and their mathematical measures that are indigenous to seemingly separate scientific fields. As McDonald and Dimmick (2003) pointed out, the concept of diversity, for example, occurs in very different disciplines ranging from economics to geography to urban planning. Further, diversity is given mathematical formulation in these disparate fields most often by the same indexes, usually some form of the Simpson index or the information theory measure.

Another construct that appears in widely different scientific disciplines is growth or diffusion and this concept is, in other fields, generally given the mathematical form of the logistic growth equation (see Banks, 1994, or Ricklefs & Miller, 1999, for a brief history of the logistic). In a volume on growth and diffusion, Banks (1994) used illustrations and examples from fields as diverse as agriculture, economics, biology, engineering, demography, and geography.

The logistic growth equation gives the rate of change(d) in population size N at time(t):

$$\frac{dN}{dt} = rN\frac{[K-N]}{K}$$

where N is the population size and K is the ability of the environment to support the population. The parameter r denotes the growth rate. The term "population" (N) is given various interpretations in different fields. In the area of media diffusion, it would be the number of individuals or households who have adopted a media innovation. In this article, we interpret K as the number of potential adopters of a new medium who have the financial resources to acquire the innovation. The larger the magnitude of r, the steeper the diffusion curve and the faster diffusion proceeds until it reaches K or the upper limit of diffusion (see Figure 1). Both r and K were traditionally considered to be constants but more recent work (see Banks, 1994) allows these parameters to take on different values. The logistic produces a growth curve that is typically sigmoid or S-shaped in form. This is illustrated in Figure 1, which shows the diffusion curve for U.S. cable television. In a later section of this article, we identify the growth rate (r) with consumer motivations or gratification utilities to adopt media. As mentioned earlier, we interpret K as the number of consumers with the monetary wherewithal to adopt a medium.

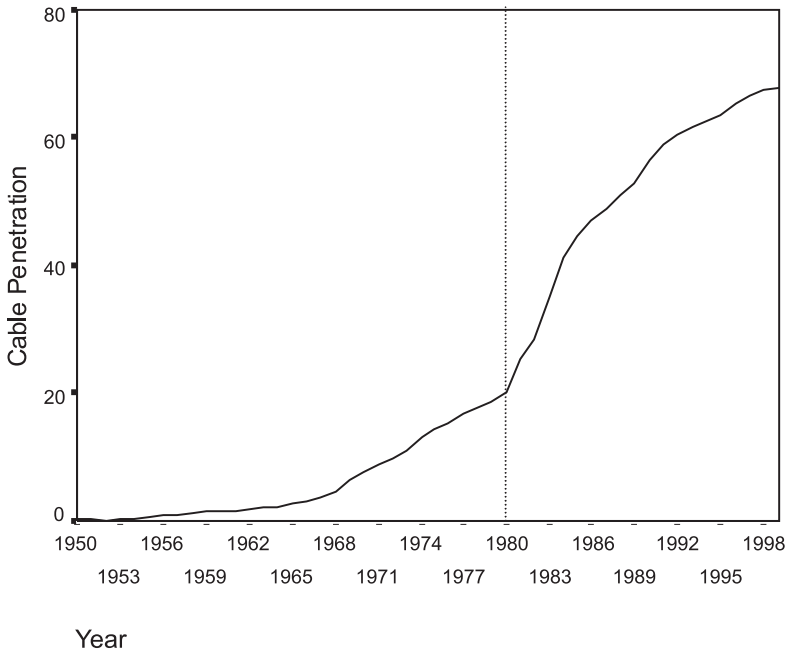

FIGURE 1 Cable penetration (1950–1999). *Note.* The data are collected from Sterling (1984) and *Statistical Abstract* (Bureau of the Census, 1980–2003). The vertical line represents the year 1980.

The fact that the characteristic sigmoid or S-shaped curve produced by the logistic is the same as that of the diffusion curve does not seem to have been realized in the field of mass communication or the subfield of media economics and management. For example, in the two classic works on diffusion in the communication field, Rogers (1995) and DeFleur and Ball-Rokeach (1988), there is no mention of the logistic. However, the relevance of the logistic equation to media diffusion has been noted by investigators in other fields. These studies have used the logistic to investigate media diffusion. Kang, Kim, Han, and Yim (1996) used the logistic to model the growth of TV in Japan and Korea; Gruber and Verboven (2001) used the logistic to assess the diffusion of mobile telecommunications in the European Union countries; and Meyer, Yung, and Ausubel (1999) used the logistic to model diffusion of records, tapes, and CDs in the United States.

Later in this article we show that the logistic provides a good fit to the diffusion of a group of U.S. communication media including radio, TV, VCR, cable, and the home computer.

THE *r*-PARAMETER: GRATIFICATION UTILITIES

If the logistic curve underlies the process of media growth or diffusion, the question that naturally arises is what is responsible for the adoption of communication media by households and individuals. The answer, from an economic perspective, is that media are adopted because they are capable of supplying utility or satisfying needs or what Dimmick (2003) called gratification utilities. For example, Van den Bulte (2000) suggested that the group of media included in his analysis may have diffused faster than other electrical durables because they required what Van den Bulte called a complementary infrastructure such as transmitters, or inquires, "did these products happen to address hitherto unanswered consumer needs" (p. 378).

Communication media do appear to have considerable utility for the consumer. Willey and Rice (1933) were perhaps the first to note that economic depression may not have catastrophically depressed the penetration of media such as radio and the telephone. McCombs (1972), however, was perhaps the first to note the greater-than-ordinary utility of the media. McCombs's analysis seemed to show that spending on the media by consumers had the same stability as spending on staple commodities such as food, clothing, and housing. McCombs's analysis was later disputed by Wood (1986). However, there are studies, aside from McCombs's analysis, that indicate the greater-than-ordinary utility derived from the media by U.S. consumers. For example, Odlum (1947) reported a Department of Commerce study that shows that during the Great Depression of the 1930s, although the demand for almost all products and services dropped, the demand for movies dropped less than the demand for seemingly necessary items such as shoes.

Dervin and Greenberg (1972) reviewed previous research and presented additional data that showed that households living below the poverty line had, nevertheless, adopted an impressive array of media. Anecdotally, the telephone and the TV set are sometimes included in government definitions of financial support. Van den Bulte (2000) found that a group of media that included radio and television diffused faster in the United States than other electrical durable goods such as microwave ovens.

Collectively, these studies point to the greater-than-ordinary utility of the communication media to consumers in the United States. The evidence suggests that *r* may, in general, be greater for communication media than for other innovations.

Consumers adopt communication media, then, because they *anticipate* deriving considerable satisfaction or gratification utility from such innovations as the radio or the cell phone. Anticipated gratification utilities are the gratifications people believe they will derive from a communication medium before they actually adopt it. These projected utilities would seem to be analytically distinct from gratifications sought (Palmgreen, 1982) that pertain to utilities people expect from a medium they have already adopted. Anticipated gratification utilities are likely formed on the basis of observation and/or trial (Rogers, 1995) of an as-yet-unadopted medium.

At this point it is not clear whether consumers' anticipated utility is expressed in the precise language of gratification utility questions used in previous studies of already adopted media or whether, on the other hand, anticipated utilities are expressed in more general ways such as a desire for more news, more movies, more sports or better ways of keeping in touch with family and friends. Hence, pilot studies will be necessary to establish the nature of anticipated gratification utilities.

The *r*-parameter of the logistic, recall, is the rate of growth. By identifying *r* with gratification utilities we are positing that the greater the attraction of consumers toward a new medium, as expressed by the magnitude of the anticipated gratification utilities, the faster the diffusion of a medium. The bandwagon effect (Rogers, 1995) may be the result of increasing opportunities for observability and trialability. As adoption increases, the greater the opportunity for the friends and families of adopters to observe and try out the medium and thereby allow estimates or anticipations of its utility. In addition, the well-known phenomena of critical mass and network externalities in the diffusion of interactive media assures that utility for an individual or household will increase with a larger number of adopters or potential interaction partners.

The *r*-value may not be constant across the diffusion history of a medium. For example, media policies at the national level may make a new medium more or less attractive to consumers during the course of its diffusion. For example, the FCC mandate requiring set manufacturers to include the FM band on radio sets prompted FM diffusion and rescued the medium from obscurity. Similarly, changes in content as a medium diffuses may alter the growth rate by changing the anticipated utility. Later we show that changes in anticipated utility seem to have spurred the growth of cable and the home computer during the diffusion of these media.

THE *K*-PARAMETER: ECONOMIC CONDITIONS

The *K*-parameter represents the number of adopting units (individuals or households) in the population with the monetary wherewithal to acquire an innovation. *K* represents a ceiling beyond which diffusion of the medium will not progress. In Figure 1, for example, *K* is the plateau in the diffusion curve. At the macro-economic level, *K* is obviously a function of economic conditions in a country that at first may enable and then may constrain diffusion of a medium. At the individual or household level (micro-economic level), economic conditions in the economy are reflected in disposable income.

Within a society, the economic conditions prevailing at a medium's birth and during the period of growth are likely to affect diffusion. In a study of the diffusion of the Internet in the United States and Europe, Bauer, Berne, and Maitland (2002) found that the economic conditions in a country as reflected in per capita income had an effect on Internet adoption. The diffusion of radio and TV in the United

States was quite likely influenced by general economic conditions. Radio made its appearance just prior to the Great Depression of the 1930s whereas TV appeared during the post-WWII economic boom. As a consequence, radio took 25 years (1922–1947) to grow from .20% of households to 91.8%, whereas TV grew from .40 to 91.0% in just 15 years from its inception in 1948. Other studies have indicated that individual or household income is positively related to diffusion. Van den Bulte (2000) found that household disposable income and unemployment influenced the diffusion of a group of household durable goods including radio and TV. Two studies on consumers who were likely to adopt new media (Dupagne, 1998; Lin, 1998) found that interest of potential adopters in new media was positively related to income.

In summary, the broad economic conditions within or between societies influence diffusion by affecting the disposable income available to individuals and households. For example, the correlation in the United States between gross national product and per capita disposable income from 1980 to 2000 is so high (.96, computed by the Cochrane-Orcutt method that takes account of positive serial correlation) as to indicate collinearity. Hence, economic conditions probably influence diffusion by affecting *K*, the number or population of individuals or households with the financial ability to adopt a medium.

Like *r*, however, *K* may vary from time-point to time-point as a medium diffuses due to changing economic conditions. K may also change, in the case of a durable good, when economies of scale in production result in falling prices. As is normally the case in diffusion, the most affluent or top 25% of households in income were the first to acquire PCs with the lowest quartile in income showing gains in computer ownership as prices have fallen (Bureau of Labor Statistics, U.S. Department of Labor, 1999). Hence, *K* may change as falling prices encourage the number of individuals or households that can afford the innovation.

The analysis thus far suggests an influence of economic conditions on diffusion through the variable of disposable income. We would posit that the ability to adopt an innovation at the household or individual level depends on disposable income in relation to price and that *K*, at any given time, is a joint function of both variables. The key to defining *K* at any particular time point in a medium's diffusion is probably the fraction or percentage the innovation price represents of a household or individual disposable income. In other words, the judgment that an adopting unit makes on the affordability of an innovation may reflect not only price but the percentage of disposable income represented by the innovation price. It may well be that in terms of the percentage of disposable income, today buyers of a cell phone or a personal computer who pay a lower price are making as significant an economic commitment as the cell phone or computer buyers of several years ago who paid much higher prices.

In summary, *K* can be defined at any time point as the proportion of the population who perceive the innovation to be affordable in terms of the percentages of

disposable income the price represents. As economic conditions change, as disposable income or economies of scale alters price, we would expect changes in the *K*-parameter.

HYPOTHESES

The questions these tentative theoretical notes have tried to answer is what economic factors comprise the *r* and *K* parameters of the logistic equation applied to media diffusion. First, we attempt to test the fit of the logistic model to U.S. media diffusion. The linear model fit is then compared to the fit of the logistic for two reasons. First, the linear model will often provide some degree of fit to distributions of quite different forms. Particularly in successful growth phenomena, the relation between penetration rate and time is strictly nonnegative. Second, the linear model fit is compared to the fit of the logistic because the linear is perhaps the simplest model and a more complex model, such as the logistic, should be preferred only if it provides a better fit to the data. Based on this rationale, we offer the following hypothesis:

H1: The logistic growth curve will be a better fit to the diffusion of radio, television, VCR, cable, and the home computer than the linear model.

In the case of the diffusion of two media—cable television and the home computer—it is possible to test hypotheses concerning the factors that constitute *r*, anticipated gratification utilities. In the case of cable, the inception of the satellite-delivered channels beginning in the early 1980s (Barnouw, 1990) should have provided an increase in anticipated gratification utilities for potential adopters that would be reflected in faster growth in the cable medium after these new channels became available. In the case of home computers, the availability of the Internet and the World Wide Web, which became available with the inception of web browsers in 1993 (Klopfenstein, 2000), is likely to have provided stronger motivation to adopt, which again, would have resulted in faster diffusion of the computer. Before the appearance of satellite-delivered channels, cable could only enhance local signals or import distant stations and a few super stations; however, before the Internet and the World Wide Web were available, there was little utility in a home computer beyond that derived from word processing, playing games, or storing family recipes.

Based on the foregoing rationale, we offer these hypotheses:

H2: A step variable representing differences in anticipated gratification utilities will be related to the diffusion of cable television.

H3: A step variable representing differences in anticipated gratification utilities will be related to the diffusion of the home computer.

Although the discussion of *K* earlier in the article stipulated that *K* depends on both disposable income and the price of the innovation, these data are not available historically for communication media. It is possible that disposable income alone will be related to media adoption. Hence, rather than offering a hypothesis we formulate the following research question:

RQ1: Is disposable income per capita related to the diffusion of radio, TV, VCR, cable television, and home computers?

METHOD

Data Sources

The data used in the research are collected from published archival data on the U.S. economy as well as media usage through the past several decades. The data on economic variables and some others (gross domestic product, disposable income, unemployment rates, the number of total U.S. households and radio households) up to 1970 come from *Historical Statistics* (Bureau of the Census, U.S. Department of Commerce, 1976), whereas the remainder comes from the series of *Statistical Abstracts* (Bureau of the Census, U.S. Department of Commerce, 1970–2003). The data for disposable income (1929–2000) are in constant dollars indexed to 1996. This variable was standardized before subsequent analysis.

The penetration rates of radio are calculated from the numbers of radio households in the United States and total households from 1922 to 1970. Those for television (1946–1963) and cable (1950–1999) are taken from Sterling's (1984) work, supplemented with data from *Statistical Abstracts*. VCR data (percentage of television households, 1980–2002) are collected from *Statistical Abstracts*, supplemented with data from Motion Picture Association of America (2004). PC ownership data (1984, 1988–2001) are collected from *Statistical Abstracts,* the *Current Population Survey* (Bureau of Labor Statistics & Bureau of the Census, 1994–2003), and previous studies on computer ownership (National Telecommunications and Information Administration, 1999; Schmitt & Wadsworth, 2002). Although the media may have originated prior to the beginning of our data series, we use the adoption data that are available. In some cases, the inception of a medium predates the available adoption data.

Curve-Fitting Procedures

A logistic model of media diffusion is tested against a linear model using the data for radio, television, and VCR penetration. Like the diffusion of innovations phenomena, media diffusion is a prolonged process. Previous research has mainly fo-

cused on the period of penetration rates from 5 to 95% (e.g., Van den Bulte, 2000). Though such analyses have contributed to the clarification of the diffusion process by eliminating various uncertain factors in the early and late stages of diffusion, they also tend to trim the data to fit the linear model better by eliminating the relatively flat position of the curves in the early and late stages of diffusion. Thus, in this study, all available data were used in curve fitting. Radio data from 1922 through 1970; television series data from 1946 through 1999; and cable data from 1950 through 1999 were used. The cumulative penetration rate was the variable used to compute the logistic curve. In our analyses, we treat both r and K as constants because we do not have measures of individual gratification utilities or measures of price and disposable income at the household level to treat r and K as variable over time.

Within-Media Comparison

Two step functions were created. The first step function, representing the inception of satellite-delivered cable channels, is set at 0 before and including the year of 1980 and at 1 after 1980. The second step function representing the inception of Internet web browsers is set at 0 up to and including the year of 1994 and at 1 after 1994. The annual increase in penetration rate of each medium was used for this analysis. Using the linear approximation for diffusion, auto-regression tests were conducted to see whether the step functions indicating the increased anticipated gratification utilities had an effect on the diffusion process of the respective media. Because not all the data for home computer penetration are available, the estimated values generated by the logistic model are used for the missing years. In both cases, computer and cable, exact maximum likelihood models were utilized, which took into account the positive serial correlation present in the data.

Similar auto-regression tests are conducted for economic variables represented by disposable income per capita. For each medium except the home computer, the period chosen for this test was from the beginning of each medium diffusion up to the year when the plateau of the diffusion curve is reached for that medium. Because the home computer is still in the process of diffusing and there is no sign of reaching a stable ownership rate, all available data were used.

RESULTS

Hypothesis 1 was fully supported by the tests conducted. As illustrated in Table 1, for all the media examined, the logistic model exhibits a better fit than the linear model.

Preliminary analysis showed that the correlation between the created two step functions and disposable income per capita are not high (for satellite channel inception, R = .4312; for Internet inception, R = .2799, both computed by the

TABLE 1
Logistic and Linear Model for Media Diffusion

Media	*Logistic Model (R^2)*	*Linear Model (R^2)*
Radio (1929–1970)	.889	.725
TV (1946–1999)	.615	.557
VCR (1980–2000)	.914	.864
Cable (1950–1999)	.991	.888
PC (1984–2001)	.984	.933

Note. All models are significant at the .0005 level. For cable, the upper bound of the logistic model is 70%; for VCR, the upper bound is 92%; for all others, it is 100%.

Cochrane-Orcutt method). Thus it is justifiable to test the main effects of the step function and the per capita income separately, as we suggested earlier.

Hypothesis 2 was fully supported. As shown in Table 2, the step function indicating the inception of satellite-delivered channels proved to be significantly related to the yearly increase in cable penetration rates ($p < .001$), explaining about 20% of the variance in the yearly increase in penetration of cable in TV households.

Hypothesis 3 also received support. The step function indicating the inception of Internet and World Wide Web is significantly related to the yearly increase in home computer ownership ($p < .05$), explaining nearly 60% of the total variance in yearly PC ownership growth (see Table 2).

The result of the tests indicates that the increase in anticipated gratification utilities is associated with an increase of penetration speed for the communication media tested. Visually, this is clearly apparent in Figure 1 in the sharp upward inflection of the cable diffusion curve after the early 1980s. Similarly, in Figure 2, the diffusion curve of the PC is relatively slow before 1994. After having reached a plateau, it moved sharply upward after the inception of the Internet and the World Wide Web.

As Figure 2 shows, the growth rate before and after the inception of the national cable channels and the web browsers is substantially different. Specifically, the average yearly growth rate for cable is .69% before the advent of the national channels and 2.5% in succeeding years (up to when the plateau in the diffusion curve was reached). Before the web browser was available, computer growth was 1.6%, as a yearly average, whereas afterward the growth rate averaged 4.2%.

TABLE 2
Auto-Regression With Anticipated Gratification Utilities

Media	*β*	*SE β*	*t*	*Approximate Probability*	*Adjusted R^2 (Cochrane-Orcutt)*
Cable	2.5347	.7058	3.5915	.0008	.1782
PC	2.7158	.4537	5.9854	<.00005	.5934

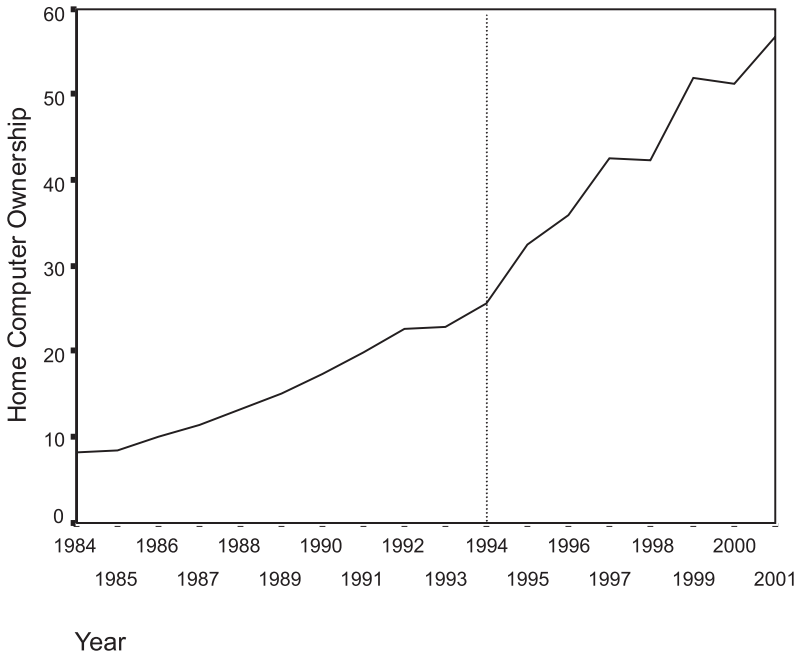

FIGURE 2 Home computer ownership (1984–2001). *Note.* Data are collected from *Statistical Abstract* (Bureau of the Census, 1980–2003), the *Current Population Survey* (Bureau of Labor Statistics & Bureau of the Census, 1994–2003), and previous research (National Telecommunications and Information Administration, 1999; Schmitt & Wadsworth, 2002). For years when accurate data are not available (1985, 1987), estimated values from logistic diffusion model are used. The vertical line represents the year 1994.

The research question received mixed answers in the analysis. As Table 3 shows, disposable income per capita was not significantly related to the annual diffusion rate for any medium tested except the home computer ($p < .005$).

It is possible that the linear model failed to represent the disposable income and the diffusion relation for the other media because of its inherent simplicity. Therefore, as a follow-up analysis, 10 curvilinear models were applied to the disposable income and diffusion rate for each of the media, including the logistic, exponential, quadratic, and logarithmic models. None of the 10 curvilinear models yielded an acceptable fit to the data. In addition, a lagged model was employed (lag = 1 year) to assess its fit to the data for each medium. The lagged model results did not provide acceptable fit to the data for any of the media. These results indicate that the lack of fit is not due simply to the model.

TABLE 3
Auto-Regression With Economic Variables

Media	β	*SE* β	*t*	*Approximate Probability*	*Adjusted* R^2 *(Cochrane-Orcutt)*
Cable (1952–1999)	0.6486	0.5069	1.2796	.2073	–.0208
Radio (1929–1947)[a]	–1.0550	0.8200	–1.2886	.2165	–.0263
TV (1948–1963)	0.8389	3.7594	0.2232	.8266	–.0001
VCR (1982–2000)	0.1666	1.3582	0.1226	.9039	.1154
PC (1984–2000)	1.3379	0.3436	3.8935	.0018	.3121[b]

[a]The data for disposable income are not available before 1929. [b]Correlation significant at $p < .005$.

The fit of the linear model to the disposable income and diffusion data may be the result of the relatively high cost of the computer compared to the cost of other media. For media such as cell phones or cable, it is possible that their cost is sufficiently low enough that increases in disposable income are not required for their adoption. The relation of such monetary variables as price and disposable income to the adoption of communication media may not be readily detectable in the aggregate data used in this article. These variables need to be explored in studies at the individual or household level.

The study demonstrates that it is possible to model media diffusion ex post facto using the logistic growth equation. However, a caveat is in order. First, it is necessary to point out that the logistic model will only fit better than the linear model for diffusion data that have reached a plateau (see Figure 1). An exponential model may provide a better fit for media in the earlier phases of diffusion.

DISCUSSION

The results of this study clearly show the feasibility of an economic theory of media diffusion based on the parameters (r and K) of the logistic growth equation by demonstrating that (a) the logistic fits the historical patterns of media diffusion in the United States; (b) the surrogate step variables for anticipated gratification utilities are related to the diffusion of cable and the personal computer; and (c) at least in the case of the personal computer, disposable income is related to diffusion.

This study was conducted with the data available at the aggregate level. Future studies should measure anticipated gratification utilities (r) and disposable income (K) at the household or individual level in sample surveys. Media diffusion curves remain largely descriptive and unconnected to predictors of diffusion. The r and K parameters, when interpreted as consumer motivations and monetary factors such as price and disposable income, respectively, provide a means of explicitly connecting theory to the form of the diffusion curve.

Meyer et al. (1999) proposed, using software called Loglet, to predict diffusion on the basis of the logistic equation alone. In this study, good fit between the logistic and diffusion data was achieved for media whose diffusion is complete. To predict the course of adoption where diffusion is incomplete—as is the case with new media—the analyst would necessarily have to estimate r and K at the initial stages of diffusion. If one were to use these estimates of r and K and the logistic equation to predict diffusion, the result would be a naive prediction that would likely contain a great amount of error because, as the theory outlined earlier states, r and K change across a medium diffusion. Although prediction is useful, prediction without explanation is intellectually sterile and may lead to erroneous predictions if the underlying causal forces are not well-understood. The logistic model could be used to predict the future course of the diffusion of home computers, or DVD players, as well as media that emerge in the future. However, to do so it will be necessary to understand the factors affecting r and K. Although the research at the aggregate level reported in this article has demonstrated the usefulness of the logistic model to an understanding of media diffusion, further research should concentrate on developing theory and measures at the individual or household level of analysis.

ACKNOWLEDGMENT

An earlier version of this article was recognized by the Stephen Lacy Top Faculty paper award by the Media Management and Economics division of AEJMC in 2004.

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