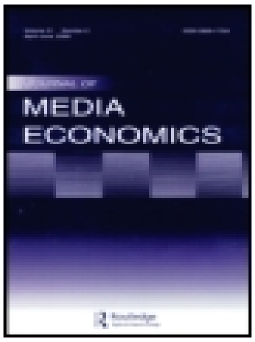

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Daniel G. McDonald & Shu-Fang Lin

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Daniel G. McDonald and Shu-Fang Lin
School of Communications
The Ohio State University

Communication researchers in general, and media researchers in particular, have devoted considerable effort to the analysis of diversity. In the area of mass communication, issues of programming, ownership, economics, and competition have all been linked to the concept of diversity or its counterpart, diversification. McDonald and Dimmick (2003) have noted that the constructs of diversity, variety, and diversification can all be measured using the same indices and indicate the same underlying concept. In addition, concentration is typically measured using the reverse of common measures of diversity and therefore also refers to the same underlying concept. For this reason, we will use the more general term of diversity in this article.

Many studies of diversity are descriptive in nature, conducted with the goal of examining diversity under particular conditions. In the case of simple descriptive studies, the reporting of a particular level of diversity using any of a number of indices is sufficient. A few studies have gone beyond these descriptive efforts to track diversity under varying conditions.

Virtually all of these studies, however, have been limited by a lack of appropriate statistical tests. As a result, the claims that can be made are typically couched in phrases such as "diversity *appears to be* different in the two conditions (or time periods, etc.)." Some studies use an "eyeball" approach in comparing data and report "significant differences," even when no statistical tests have been made. However, a visual comparison of diversity levels is very similar to visually comparing means; statistically significant differences cannot be determined by the level of diversity any more than an examination of means can be used to assess statistically significant differences in mean values.

Requests for reprints should be sent to Daniel G. McDonald, School of Communication, The Ohio State University, 154 N. Oval Mall, Columbus, OH 43210. E-mail: mcdonald.221@osu.edu

If the field of communication research is to advance beyond descriptive studies of diversity, it will be important to assess true statistically significant differences so that theoretically driven hypotheses can be tested, and variation in diversity may be attributed to specific characteristics or conditions. This article reviews the method and use of statistically significant differences in diversity. We first examine the idea of dual-concept diversity, then examine Simpson's D (Simpson, 1949) and its extensions, explain the conditions in which D or its variants might be applied, and then use U.S. network television data to illustrate the utility of powerful diversity measures.

DUAL-CONCEPT DIVERSITY

We follow Junge's (1994) notion that diversity is a two-dimensional concept (see also McDonald and Dimmick, 2003). The first dimension is typically a set of discrete classification categories; the second is the number or proportion of objects allocated to these classifications. Thus, for example, in a study of diversity in media ownership, race of the owners of media outlets might be the categorical dimension, whereas the second dimension would be the percentages or proportions of owners of each race, with the totals adding to 1.00 or 100%.

A measurement goal for researchers studying diversity is to incorporate a diversity measure that expresses these two dimensions in a single number. In essence, that number should reflect the interaction of the number of categories with the distribution of elements within those categories. Typically, that interaction has been conceptualized such that a perfectly flat distribution of objects allocated to categories should be the most diverse, and a distribution in which all of the objects are allocated to one category is the least diverse.

Although single-concept measures have been used in the literature (e.g., DeJong & Bates, 1991; Dominick & Pearce, 1976; Long, 1979), we will not consider these measures. McDonald and Dimmick (2003) point out some of the problems with interpretability of any single-concept measure of diversity. Because there is no shortage of dual-concept measures (McDonald & Dimmick [2003] describe 13 dual-concept measures), this article limits consideration to dual-concept measures.

For this study, we follow the logic expressed in McDonald and Dimmick (2003), that a measure of diversity should have the two following highly desirable characteristics: (a) the measure (or its standardized version) should vary between 0 and 1.00, with 0 indicating no diversity and 1.00 indicating the most diverse distribution possible, and (b) adding additional categories to which no population members are assigned should not change the value of diversity. To this list we add a third desirable characteristic: (c) variance within the measures should be partitionable so that analyses may focus on contributions of other variables to diversity or tests for statistically significant differences. Of the 13 measures reviewed by McDonald and Dimmick (2003), only Simpson's D and Shannon's H have had sufficient study to be known to have these three characteristics (Agresti & Agresti, 1977; Good, 1953; Teachman, 1980).

SIMPSON'S D

Simpson's D $\left(\hat{D} = 1 - \sum_{i=1}^{k} \hat{p}_i^2\right)$ has one additional characteristic that Shannon's H does not have—ease of interpretability. Simpson's D is obtained by summing the squared probabilities (the p_i's) from all the categories and subtracting that sum from 1.0. The diversity value obtained is equivalent to the probability that two of the objects of classification (the elements), chosen at random, would be in different categories. If all the objects are in one category, then the probability is 0, as is the diversity measure; if all of the objects are in different categories, then Simpson's D is 1.0, which corresponds to the probability that all the objects are in different categories. For this reason, we prefer the use of Simpson's D, and will use D and an extension, Lieberson's D_b (Lieberson, 1969), for illustrative purposes in this article. Calculation and hypothesis testing formulae are available in the appendix.

Simpson's D is a very strong candidate for a general measure of diversity. The fact that it varies between 0 and 1, and that its value at a given point is also a readily understandable probability, seem to be inherent strengths of the measure that no other diversity measure offers. It is therefore useful and straightforward in simple descriptive studies in which the researcher is interested in a single measure of diversity. In addition, the measure is readily interpretable across studies because it always indicates the same thing: the probability that two elements, selected at random from the population, are in different categories.

An additional strength is provided by a standardized version. One of the continual difficulties in social science research is that the categories of classification may be different for different studies, even those studies examining the same phenomenon. One difficulty in interpretation of a probabilistic measure is that, in practice, we almost never have the same number of categories as elements to be classified, so the probability will not be 1.0—the maximum is determined by the number of categories: max = (k - 1)/k, where k = the number of categories. Thus, a population with 10 categories has a greater potential for diversity (max = .9) than a population with 3 categories (max = .67). However, a standardized version of D can be calculated quite easily by dividing by its theoretical maximum: $D_Z = D/(1 - 1/k)$, and that transformation yields a value that corrects for different numbers of categories in different studies, making comparisons across studies a simple task.

In addition to making simple comparisons of the D value obtained in different studies or for different groups, and so on, the variance of D is known and can be calculated easily with a hand calculator (see appendix). Because of this, confidence intervals can be constructed around the obtained values of D, just as they can with means, percentages or probabilities. In addition, simple hypothesis tests involving differences between groups are easy to conduct, as are tests of null hypotheses of specific values (e.g., a value from a previous study).

There have also been a number of extensions of D to aid specific comparisons or hypotheses. The first extension of D we will consider was developed by Lieberson (1969), and is generally referred to as Lieberson's D_b. Lieberson's D_b is used in the case of two different populations and represents the probability that two elements selected randomly, one from each population, are classified differently on the categorical variable (Agresti & Agresti, 1977). Such a measure is highly useful in comparing two populations to see how similar or dissimilar they are in the categories of classification (see appendix).

The second and third extensions of D are used in situations in which populations are classified according to two or more nominal variables (Agresti & Agresti, 1977). The second extension is known as Multivariate D (D_{multi}), and is used in cases in which a single population may be classified using two different variables. D_{multi} represents the average proportion of the two variables on which the two elements differ in classification (Agresti & Agresti, 1977; Lieberson, 1969).

The third extension is referred to as Multivariate D_b, $D_{bmulti,}$ also developed by Lieberson (1969). $D_{bmulti,}$ is similar to D_{multi} and also represents the proportion of different classifications of a sampled pair on two variables, but, in this case, the pairs are chosen from two different populations. D_{multi} and D_{bmulti} are thus similar to D and D_b, respectively, except that they allow multiple variables of classification. Although the calculation is correspondingly more complex, it may still be done with a hand calculator or spreadsheet (appendix).[1]

APPLICATION OF POWERFUL DIVERSITY MEASURES

For this article, we examine diversity in U.S. television programming from 1986 to 2000, a period that saw the growth of a number of new networks through cable and broadcast, or a combination of the two. For our purposes, we consider a new network to be successful if it offers at least one program that attracts an audience rating high enough to be included in the Nielsen yearend summary of average ratings for the year. We illustrate the range of diversity over the study years and assess the extent to which the successful new networks affected overall diversity of television programming offerings and the diversity of programming on the three traditional networks.

[1]Interested readers who prefer to use Shannon's H as a measure are referred to Teachman (1980), who provides the statistical properties and interpretation for Shannon's H.

In the competitive arena of television programming, one can imagine several different scenarios when new networks become successful. On one hand, if they become successful with an innovation of a particular type of program, the traditional networks may imitate that program. Typically, the rise of a new program type signals the demise of a different type, and so diversity could remain fairly constant even while the dominant program types exhibit change (Dominick & Pearce, 1976; McDonald & Dimmick, 2003; McDonald & Schechter, 1988).

On the other hand, the traditional networks may not imitate a competitor's innovative format, and, if that is the case, system diversity should increase slightly. If each new competitor specializes in an innovative new format, and the traditional networks do not imitate those new formats, overall system diversity should increase substantially. Another scenario might suggest that traditional networks may innovate under competition, and so traditional networks may grow more diverse regardless of whether the new networks are innovative or not.

However, it could also be the case that the new networks may be generalists and offer program types that are already present; in such a situation, if the new networks offer those program types in approximately the same distribution as traditional networks, overall diversity would not change. An altogether different process could occur in which, as new, specialist networks become successful, traditional networks become specialists as well. In such a case, the individual network diversity will be low, but overall system diversity could be high.

These scenarios all point to a basic issue in assessing system-level diversity. High system-level diversity can be achieved if all the networks are generalists, all specialists, or some generalists and some specialists. Policy related to program offerings should take into account that there are multiple ways to achieve diversity. We use the U.S. television network system to illustrate this point and to move diversity analyses beyond descriptive studies.

The research literature has addressed this issue in limited ways. Owen, Beebe, and Manning (1974, p. 130), for example, appear to assume that the addition of a fourth network to the three traditional networks should increase program diversity. Long's (1979) historical study of the early 1950s (when the DuMont network competed with ABC, NBC, and CBS) suggests that the decline of a fourth network lead to lower program diversity. However, Long's conclusion, derived from studying the first years of a developing medium, may not be applicable to the situation of competition within a mature medium.

The question typically is described in terms of competition. Litman (1979) analyzed U.S. television in the 1970s, a period of increased network competition, and found that increased competition led to increased diversity. A number of studies however, have found the opposite relation when examining competition and diversity (Lin, 1995a, 1995b; Liu, 1997).

The key may be in a more careful specification of the concepts involved in the relationships. Competition may be from new competitors, or it may be within the oligopoly itself. Litman's (1979) finding of increased diversity related to competition studied competition within the oligopoly (i.e., between the traditional networks). Lin (1995a) compared a period of competition within the oligopoly (the 1970s) to a period of competition with new alternatives from outside the oligopoly (cable and VCRs in the 1980s), and found a decline in diversity among the networks. An additional study by Lin (1995b) also found that increased external competition reduced diversity. Li and Chiang (2001) again found that diversity of network programming declined in the advent of competition from satellite and cable television.

Findings from studies of media other than television offer similar results. Burnett (1992) found that competition within the radio industry was negatively related to diversity; Berry and Waldfogel (2001) found that increased concentration of radio station ownership increased diversity of radio formats within a market, as did Rogers and Woodbury (1996). Similarly, a study of the videocassette industry by Hellman and Soramaki (1985) found a negative relationship between competition and diversity.

We suggest that these results, taken together, suggest that competition within an oligopoly leads to increased diversity of programs within that oligopoly, whereas competition from outside competitors leads the members of the oligopoly to rely on "tried and true" measures to maintain market share, thus decreasing diversity within the members of the oligopoly. We thus should have a television system in which overall system diversity will increase under competition (due to the innovation of new networks) while diversity within the traditional networks will decrease.

We therefore offer the following hypotheses for the U.S. television industry during the period of 1986 to 2000:

H1: Overall system diversity will increase in the period between 1986 and 2000.
H2: Traditional network diversity will decrease between 1986 and 2000.

As described earlier, there are multiple ways in which system-level diversity can be affected. We also offer the following research questions to address patterns of diversity that may be developing within the television industry.

RQ1: Do the new networks offer more, less, or about the same level of diversity in programming as traditional broadcast networks?
RQ2: Are the successful new networks specialists or generalists in their offerings?
RQ3: Has the advent of new networks altered the degree of specialization of the three traditional networks?

METHOD

We included every network program listed in the A. C. Nielsen yearend summary of first-run programs offered on network television (published in May or early June in a number of sources).[2] From 1986 through 1988, only programs in the three traditional broadcast networks were listed in the Nielsen rating summary: ABC, NBC, and CBS. In the late 1980s, the Fox network was created from a number of independent television stations. With diffusion of cable, these stations began to reach a wide audience. By 1989, shows on the Fox network were listed in the yearend summary. In the 1990s, the UPN, WB, and PAX cable network programs appeared in the list (see Figure 1).

We classify Fox, UPN, WB, and PAX as new nontraditional networks for this study. The impact of the new networks is apparent in the number of programs appearing in the Nielsen lists, which increased dramatically from 1986 to 2000. In 1986, the Nielsen summary included 81 programs; in 2000, the summary included 196 programs (Table 1).

Program type was added to the lists of programs in an iterative fashion. First, all of those programs included in Brooks and Marsh (1999) were given the program type listed. If a program was not listed in Brooks and Marsh, two internet resources provided a program type for the bulk of the remaining programs: TV Tome (http://www.tvtome.com/) and All Your TV (http://www.allyourtv.com/showguides.html). After consulting these three sources, a few programs were still not classifiable, but a direct search of the Internet by the program name yielded a program type for all of the remaining programs.

Because many of the program type classifications are idiosyncratic or highly specific (the earlier mentioned method yielded 151 program types), the authors developed a general program type scheme using 24 program types and combined the 151 types into the 24 general types.[3] These 24 types were used in the present analysis.

ANALYSIS

Simpson's D was computed for each year of the study period (1986–2000) in several different ways: overall system diversity (based on the distribution of all pro-

[2]Sources used to obtain the yearly listings were yearend averages published in *Electronic Media* and *Variety*. Program types were obtained from Brooks and Marsh (1999), TV Guide online, tvtome.com, and allyourtv.com.

[3]The program types used in this study were Adventure, Animal, Anthology, Game, Cartoon, Comedy, Detective, Documentary, Drama, Foreign Intrigue, Fantasy, Informational, Movie, Music, Newsmagazine, Police, Public Service, Reality, Religion, Science Fiction, Sports, Supernatural, Variety, and Western.

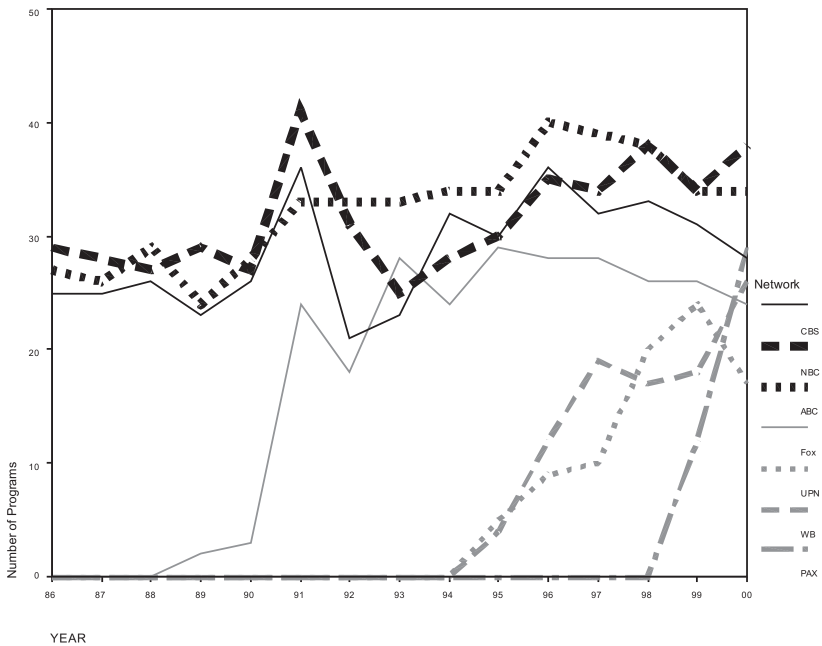

FIGURE 1 Number of programs by network.

TABLE 1
Television System Diversity in 1986 and 2000

Variables	*1986*	*2000*
Traditional networks		
CBS	25	28
NBC	29	38
ABC	27	34
Number of programs	81	100
Traditional net diversity	.790	.770
Variance of diversity	.002	.031
New networks		
Fox	0	24
UPN	0	17
WB	0	26
PAX	0	29
Number of programs	0	96
New net diversity	—	.840
Variance of diversity	—	.017
Total		
Number of programs	81	196
Total system diversity	.790	.820
Variance of diversity	.002	.004

grams in the yearly summary of programs), individual network diversity (diversity for each network, each year it was on), traditional network diversity (diversity of all programs offered by ABC, NBC, and CBS each year), and new network diversity (diversity of all programs offered by Fox, UPN, WB, and PAX). Because all comparisons involve the same number of program type categories, there is no need to standardize D. In addition, because there are 24 program types, the maximum possible D value is .96; a standardized value of D will be very close to the unstandardized values presented here.

Lieberson's D_b is used to measure between-network diversity. Lieberson's D_b also offers ready interpretability, because it represents the probability that two elements drawn randomly, one from each population, are classified differently. In the special case in which the two populations have identical distributions, D_b is equivalent to D. The appendix includes the details regarding confidence intervals and hypothesis testing with D.

RESULTS

Our first hypothesis suggested that overall system diversity should increase between 1986 and 2000. Figure 2 presents a graphical illustration of the trend in di-

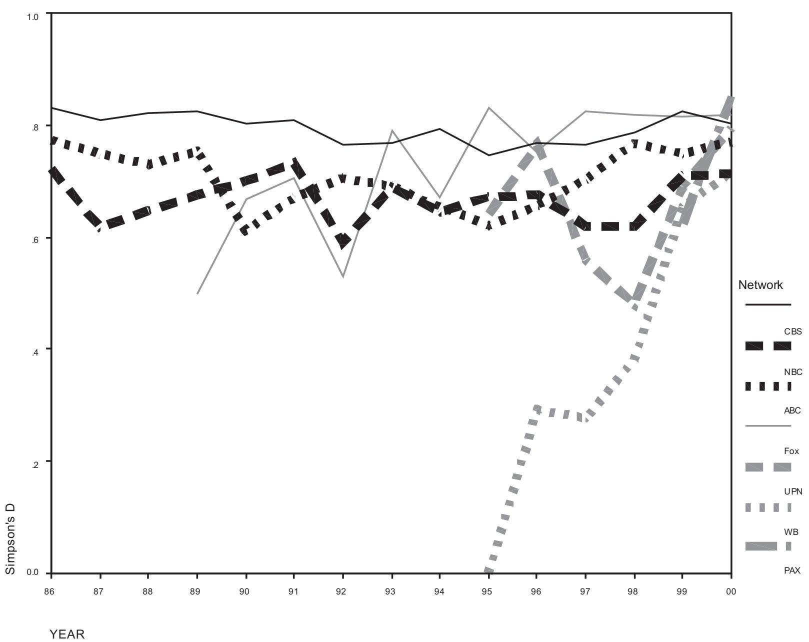

FIGURE 2 Diversity levels for all seven networks.

versity between 1986 and 2000 for each of the seven networks, and Figure 3 provides an illustration of the aggregate diversity for the traditional networks, the new networks, and overall system diversity. A visual examination of these figures suggests change in the system. It appears that the new networks very quickly become as diverse as traditional networks. In fact, from 1993 to 2000, the Fox network, one of the new networks, was the most diverse of all.

Overall system diversity (the solid line in Figure 3) appears to decline from 1986 to about 1993, and increase from 1997 onward, a time period coinciding with the growth of the new networks. All three lines (overall, traditional and new networks) increase during that time period. As is evident from an examination of Figure 3, there appears to be a slight increase in diversity for traditional networks, but the diversity level in 2000 is not as high as overall system diversity or diversity among the new networks. This suggests that the new networks are more diverse than traditional networks, and the success of the new networks has been the major factor responsible for the increase in overall system diversity during the study period. Traditional network diversity appears to decline slightly during the study period.

To examine these changes in depth we turn to statistical tests. Table 1 presents diversity data between 1986 and 2000. In 1986, the traditional networks (the only

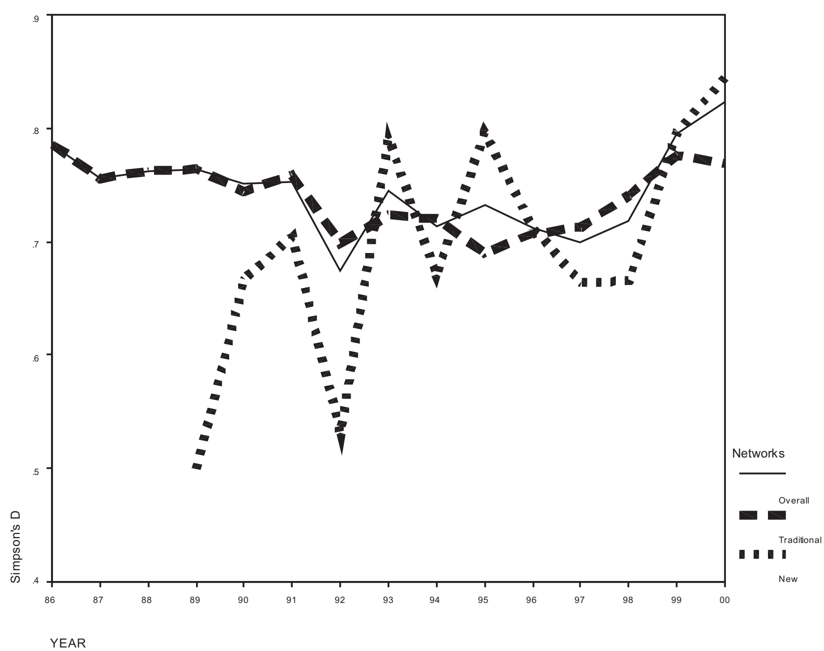

FIGURE 3 Diversity levels for the overall system, traditional and new television networks.

networks appearing in the yearend summary) had a diversity level of .79 with 81 programs. In 2000, the traditional and new networks combined had a diversity level of .82 with 196 programs in the summary. A test for a significant difference (simply a test that the confidence interval in the difference in diversity between 1986 and 2000 did not include zero—see the appendix) between system diversity in 1986 and 2000 was significant—the 95% confidence interval is (.02, .04), indicating that overall system diversity was higher in 2000 than in 1986.

Our second hypothesis suggested that there should be a change in diversity of programs offered by the traditional networks. Again, Table 1 provides the relevant data—the hypothesis test for a difference is simply a test between the 1986 value (.79) and the 2000 value for the traditional networks (.77). In this case, the 95% confidence interval for the difference ranges between -.03 and .04, which means that zero is included within the confidence interval, so we cannot reject the hypothesis of no difference.

Thus far, our tests have shown a significant increase in overall system diversity, but no change in diversity for the traditional networks. Our first research question asked whether the new networks offer a different level of diversity in programming than do the traditional networks. In this case, the comparison is a diversity level of .77 (traditional networks in 2000) compared to a diversity level of .84 (new networks in 2000). The 95% confidence interval for the difference between the two types of networks is (.03, .11), which does not include zero. We therefore conclude that there is a significant difference between the new networks and traditional networks, with the new networks more diverse than traditional networks.

As previously mentioned, greater diversity can be obtained with networks being either generalists or specialists, so we tested for specialization of the new networks (Research Question 2). We first calculated individual network diversity for all seven networks and system diversity separately for the traditional and new networks. If greater diversity has been achieved by new network specialization, then Simpson's measure should be relatively low for each of the new networks, while their combined diversity should be high. If they are generalists, then we should expect no significant difference between an individual network's diversity level and the overall diversity of the group in which it belongs.

Table 2 provides the diversity level for each of the seven networks in 2000, as well as overall system diversity for the traditional and new networks and between-group diversity for traditional and new networks. Our first test showed that only the WB network diversity level was significantly different from the overall new network diversity level of .84. In this case, the WB network diversity level, at .72, was significantly lower, suggesting that WB offers more specialized programs, whereas the other new networks are more general in their offerings.

Other data related to specialization is presented in the network/own group and network/other group comparison sets of D_b statistics presented in Table 2. Although we do not present all the statistical comparison tests here (because of the

TABLE 2
Network Diversity

	Traditional Networks			New Networks			
Variables	*ABC*	*CBS*	*NBC*	*Fox*	*PAX*	*UPN*	*WB*
Within-group diversity							
Network diversity 1986	.77	.83	.72	—	—	—	—
Network diversity 2000	.77	.80	.71	.82	.85	.80	.72[a]
Overall within-group diversity 1986		.79			—		
Overall within-group diversity 2000		.77			.84[b]		
Between-group diversity							
Network/own group 1986 Lieberson's D_b	.57	.62	.57	—	—	—	—
Network/own group 2000 Lieberson's D_b	.77[c]	.80[c]	.75[c]	.85	.80	.84	.89
Network/other group 2000 Lieberson's D_b	.85	.84	.84	.83	.82	.78	.92
Traditional/new networks 2000 Lieberson's D_b			.84				
1986 multivariate Simpson's D_{multi}		.73			—		
2000 multivariate Simpson's D_{multi}		.72			.81		

[a]Indicates a significant difference between diversity for the WB network in comparison to overall diversity of the new networks. [b]Indicates a significant difference between traditional and new network diversity in 2000. [c]Indicates a significant difference in between-group diversity in comparing 1986 to 2000.

number of comparisons), we present the data for expository purposes and provide two of the possible tests. In the network/own group 2000 comparisons, the D_b figures range from .77 to .80 for the traditional networks, and .80 to .89 for the new networks, suggesting that there is more specialization among the new networks than among the traditional networks (higher D_b values indicate a greater degree of specialization). In the network/other group comparison, values range from .84 to .85 for traditional networks, and .78 to .92 for the new networks, suggesting that a network like WB (with a value of .92) is highly differentiated from the traditional networks, whereas UPN, with a between-group diversity value of .78 comparing it to traditional networks, and .84 comparing it to the new networks, is more like the traditional networks in its offerings than it is like the new networks in their offerings ($p < .05$).

Our final research question asked whether the advent of successful new networks had altered the degree of specialization of the traditional networks. To test this proposition, for both 1986 and 2000, we calculated Lieberson's D_b (between-group diversity) for each of the traditional networks in comparison to the overall traditional network diversity. D_b provides an index of the extent to which the networks "mirror" each other in their distributions. If they are specialists, D_b will be high, as there will be little similarity in the proportion of programming allotted to various program types. If the networks have altered their degree of specialization as a result of the new networks, we should find a significant difference between the 1986 and 2000 between-group diversity levels. As indicated in Table

2, all three networks have significant differences in comparing 1986 and 2000, supporting the idea that the traditional networks have had to specialize in the wake of competition from new networks. This is especially interesting in light of the test involving analysis of overall diversity levels, which have not changed.

We confirmed the conclusion of specialization without a change in system diversity with a second test designed to assess change in overall diversity of the three traditional networks. Table 2 also provides the D_{multi} values for the three traditional networks in 1986 (.73) and 2000 (.72). The D_{multi} treats network as a variable, rather than as a population, and tests for overall diversity within levels of that variable. A test of differences shows no statistically significant difference between the two years, again suggesting that the traditional networks have not altered their level of diversity as a result of the success of new nontraditional networks, even though they are more specialized.

DISCUSSION

As diversity continues to be of central concern in communication research, it is important for communication scientists to pay careful attention to the concept and its measurement. There were a number of substantive findings from our illustrations that have implications for policy as well as for understanding network programming. Using national U.S. television network program data from 1986 to 2000, we have explored five research questions and have been able to get a reasonable grasp of the relation between network competition and program diversity during this time period.

What we have found is that the new networks have resulted in more than double the number of programs classified in the Nielsen annual summaries of television, and there has been a concomitant increase in overall system diversity. Although overall diversity has increased, the traditional television networks have remained fairly constant in their level of diversity. The new cable and other nontraditional channels rose quickly to levels comparable to those of the traditional broadcast networks and, within a few years, surpassed the traditional networks' program diversity.

In light of the rise of the new networks, the traditional networks have apparently begun to specialize somewhat; all three traditional networks show greater between-group diversity in 2000 than was evident in 1986.

We discussed several possible ways in which system diversity can increase. One of these ways is to have a number of networks that specialize in particular content types. Our tests showed that this has not been the case for traditional networks taken as a group, but appears to be so for all of the new networks. That is, even though the traditional networks have each specialized, their content repertoire has not grown more diverse, suggesting that, as a group, traditional network content is about as diverse as it was before the advent of the new networks, but individually they appear to be specializing in certain content types.

In terms of the new networks, the WB network is significantly less diverse than the other new networks as a group, and the between-group diversity involving WB and traditional networks was not significantly different from overall diversity for traditional networks. However, all of the new networks, including the WB, are significantly more specialized than are the traditional networks.

The other new networks all appear to have a broad range of content, suggesting that the newer networks, which are more diverse than traditional networks, must attain that diversity through emphasizing program types that are underemphasized in traditional networks—bringing greater diversity to the system while maintaining specialization.

Although researchers have talked about the possibility of a television of abundance for decades now, and of the implications of cable for program diversity, this study has attempted to document how the past decade and a half have played out in terms of that diversity. Although it is clear that there are many cable and other networks that are highly specialized (HGN, the Food Network, etc.), they are not yet represented in annual Nielsen summaries. The new networks that are represented—that is, those that have developed programs that attract large enough audiences to be included in the summaries—are clearly generalists. Predictions that technology has ended or will end “mass” communication are not yet borne out—mass communication channels still dominate television entertainment.

This article has sought to suggest how the use of one of the better measures of diversity, Simpson’s D, has a number of advantages over descriptive measures, including its potential in statistical analyses. We hope that the results obtained from our analyses, and the implications of the results for understanding network program diversity in the era of competition, offers a strong rationale for the use of more advanced techniques, not only in the study of network television, but in many areas in which diversity plays a key part.

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APPENDIX
Formulas for Diversity and Statistical Inferences

1. To calculate Simpson's D and compare D for two groups:

a. Calculation of Simpson's D

$$\hat{D} = 1 - \sum_{i=1}^{k} \hat{p}_i^2$$

where k refer to a number of categories in the distribution; p_i is the proportion in the ith category ($i = 1, \ldots, k$).

b. Calculation of confidence interval for two groups

$$(\hat{D}_2 - \hat{D}_1) \pm Z_{a/2}\sqrt{(\hat{\sigma}_1^2/n_1)+(\hat{\sigma}_2^2/n_2)}$$

where

$$\hat{\sigma}_1^2 = 4\left[\sum_{i=1}^{k_1}\hat{p}_i^3 - \left(\sum_{i=1}^{k_1}\hat{p}_i^2\right)^2\right]$$

$$\hat{\sigma}_2^2 = 4\left[\sum_{i=1}^{k_2}\hat{q}_i^3 - \left(\sum_{i=1}^{k_2}\hat{q}_i^2\right)^2\right]$$

n_1 is the number of observations in the sample of the first population. k is the number of categories in the distribution. p is the proportion in the ith category ($i = 1, \ldots, k_1$), and D_1 is the index of diversity.

n_2 is the sample size selected from another population and divided into k_2 categories. The proportions corresponding to the categories are $\{q_i, 1 \le i \le k_2\}$, and the index of diversity is D_2.

2. To calculate Lieberson's D_b and compare two groups:
a. Calculation of confidence interval

$$D_b \pm Z_{a/2}\sqrt{\frac{\sum_{i=1}^{k}\hat{p}_i\hat{q}_i^2}{n_1}+\frac{\sum_{i=1}^{k}\hat{q}_i\hat{p}_i^2}{n_2}-\frac{(n_1+n_2)(1-\hat{D}_b)}{n_1 n_2}}$$

where

$$D_b = 1-\sum_{i=1}^{k}\hat{p}_i\hat{q}_i$$

$$\hat{\sigma}_b^2 = \left(\frac{n_1+n_2}{n_1}\right)\sum_{i=1}^{k}\hat{p}_i\hat{q}_i^2 + \left(\frac{n_1+n_2}{n_2}\right)\sum_{i=1}^{k}\hat{q}_i\hat{p}_i^2 - \frac{(n_1+n_2)^2}{n_1 n_2}\left(\sum_{i=1}^{k}\hat{p}_i\hat{q}_i\right)^2$$

n_1 is the number of observations in the sample of the first population. k_1 is the number of categories in the distribution. p_i is the proportion in the ith category ($i = 1, \ldots, k_1$). n_2 is the sample size selected from another population and divided into k_2 categories. The proportions corresponding to the categories are $\{q_i, 1 \le i \le k_2\}$.

b. Calculation of test statistic

$$Z = \sqrt{n_1+n_2}\left(\hat{D}_b - D_b^{(0)}\right)/\hat{\sigma}_b$$

3. To calculate the Multivariate D:

a. Calculation of confidence interval

$$\left(\hat{D}_2 - \hat{D}_1\right) \pm Z_{a/2} \sqrt{\left(\hat{\sigma}_1^2 / n_1\right) + \left(\hat{\sigma}_2^2 / n_2\right)}$$

where

$$\hat{D} = 1 - \left(\sum_{i=1}^{k_1} \hat{p}_i^2 + \sum_{i=1}^{k_2} \hat{p}_i^2 + \ldots + \sum_{i=1}^{k_m} \hat{p}_i^2 \right) \Big/ m$$

$$\hat{\sigma}^2 = \left(4/m^2\right) \left[\sum_i \hat{p}_i \left(\hat{p}_{i_1 \ldots} + \ldots + \hat{p}_{\ldots i_m} \right)^2 \right] - 4\left(1 - \hat{D}\right)^2$$

m is the number of variables. The lth of the variables has k_l levels, $l = 1, 2, \ldots, m$. p_i is the proportion of the population in cell i.