Executive Summary

This paper has practical implications in three areas of application in corporate management:

- strategy research
- corporate planning
- governmental regulation.

The authors’ review of the literature reveals a trend toward an increased use of the uncalibrated Herfindahl Index by regulators and of the uncalibrated Entropy measure by researchers. This trend involves considerable risks if it continues unabated into the new century. In the latter domain, the lack of discrimination power of current indices of concentration or diversification is becoming a major problem in that limit values specified by regulations are based on biased indicators. These are compounded when the Herfindahl Index becomes the sole anti-trust instrument for industry regulation as has been codified in the US by the guidelines jointly issued in 1992 by the Federal Trade Commission and the US Department of Justice.

Complementing the empirical investigations published in the research literature over the last ten years, this paper examines the existing measures of industry concentration or product-line diversity on theoretical grounds and found them wanting in certain respects:

- There is a lack of calibration with respect to the effect of the number of product lines or scope variable n.
- Diversification studies are distorted by the fact that these diversity measures of firms with several product lines become unreliable and biased toward the high end of their range.
- There is a lack of sensitivity with respect to capturing intermediate load distributions between the two extreme cases of a single firm (or product) or of a very large number of them.

This article presents clear criteria for designing diversity indices and gauging them. Industrial Organization (IO) economists appear to have been suspicious of these problems for a number of years, yet very little has been done to warn regulatory agencies and strategy researchers of the problems inherent in their increasing use of the uncalibrated indices. In contrast, this article develops two intrinsically calibrated indices, A1 and A2, for use by researchers, strategic planners, and industry regulators. An ideal composite measure should incorporate both the effect of cardinality or scope and the effect of shape or distribution. The existing indices bundle these two effects; the objective of this research is to ‘unbundle’ them.

Most large North-American firms tend to be multi-product corporations for which the measurement of product-line diversity as well as social diversity will be affected by the above considerations. Chances are that the same holds true in the Indian context. However, this is partly an empirical question that could be further investigated by follow-up studies on databases such as Capital-Line and Prowess, leading to some useful information for strategic and legal considerations.
The related issues of market structure, corporate growth, product-line diversity, and diversification strategy have been central to strategic management. As we turn into a new century, it is essential to keep in mind that an adequate measurement of firm diversification is a requisite to the development of a sound theory. First, diversity is a core concept of strategic research. Also, the study of diversity is now expanding into new areas: the financial literature is concerned with diversification (Aggarwal and Samwick, 2003); resource diversity is now a consideration in information science research (Bharadwaj, 2000); it is also a concern in organizational research (Barkema, Baum and Mannix, 2002). The concern with social diversity and its measures is intensifying because of the lingering shock of the September 11 attacks.

Do we need to develop new measures of diversification for the new century? While some authors still use classification schemes such as the one pioneered by Rumelt, the strategic literature leans increasingly toward using continuous indices based on the SIC (Standard Industrial Classification) or the newer NAICS (North American Industrial Classification System) industrial classifications. During the two ending decades of the past century, the debate has shifted from justifying the use of continuous measures (Jacquemin and Berry, 1979; Montgomery, 1982) to determining the exact form or variant to be adopted (Acar and Sankaran, 1999; Baysinger and Hoskisson, 1989; Chatterjee and Blocher, 1992). It is no longer a matter of why but how to best use continuous measures.

Specifically, this paper proposes that the proper calibration of an index or measure is an essential ingredient to its successful use, be it for regulatory or research purposes. By now, the academic debate concerning the adequacy of concentration or diversification measures is spilling over into application areas. In anti-trust regulation, the revised Horizontal Merger Guidelines jointly published by the US Department of Justice and the Federal Trade Commission (1992) promote the use of the Herfindahl-Hirschman Index (HHI or “H”) for gauging industry concentration. This marks a shift from these agencies’ earlier reliance on straight concentration ratios (Scherer, 1970). In addition, court cases now often rely on the HHI (e.g., United States v. Heileman Brewing Federal Supplement, 1983). This paper’s contribution is to explain some of the potential difficulties entailed in using continuous measures in terms of methodologically driven consistency requirements.

**BACKGROUND**

**The Need for Continuous Measures**

The thrust of this paper is on preventing potentially damaging consequences in three major application areas. First, in strategy research, diversification studies should not be distorted by the fact that the diversity measures become biased and unreliable. Second, corporate planners need measures that are robust, symmetrical, and not skewed towards either end of their range. Third, because they could face complaints or counter-suits, regulatory agencies should have available to them measures of concentration or diversity about which no suspicion of distortion could be imagined.

Admittedly, the aggregate nature of data available for strategic research is a major source of inaccuracy. Yet, there is no need to compound data inaccuracies with additional disturbances due to the indices employed for measuring product-line diversity. While data availability and quality are not within the control of strategy planners and researchers, the proper choice of a continuous index and its ‘calibration’ could be easily undertaken as we propose to show.

There seems to be a decreasing interest in both concentration ratios and the older measures of inequality such as the Lorenz-curve-based “Gini indices” (Needham, 1978; Waterson, 1984) in favour of explicit concentration or diversification measures. This theoretical call favouring continuous measures was followed by the practitioner-oriented literature in the 1980s; with only a few discordant voices, it promotes the use of the HHI. Conversely, the very recent trend of the 1990s shows many researchers now using the Entropy measure (E), sometimes in conjunction with the HHI but often by itself (Raghunathan, 1995). As noted by Montgomery (1982) and other Industrial Organization (IO) economists, continuous measures offer considerable computational advantages over categorical schemes or simple product counts. These advantages have recently become more important in view of the availability of Compustat and similar databases (Montgomery, 1982).

The only remaining question is how to select among these quantitative measures. A couple of alternative indices also exist. The remaining serious contenders, Kwoka’s Dominance Index and the Hall-Tideman-Rosenbluth Index still find some advocates in IO usage and are evaluated in the next section. It is often suggested (e.g., Hall and Tideman, 1967; Marfels, 1971a and
b) that the choice of a concentration measure should depend on the purpose of the measurement and the researcher's perception of the weighting scheme appropriate for the industry in consideration. However, as Horvath (1972a and b) observes, this would make measuring diversity or concentration subject to arbitrary choice by the user. This would be a step back from the obvious need to have a common standard of concentration measurement for regulatory and other purposes.

**Methodological Requirements**

A major concern of the present paper is the discriminatory power of the measures used in regulatory practice. Hall and St. John (1994) show that the choice of the measure of firm diversification really matters to planners and regulators — a point made earlier by Kwoka (1981). Historically, the process of developing a measure in building an index entails consecutive steps. The earlier steps consist of theoretical development and the latter empirical validation.

The earlier steps of theoretical development have been largely looked at in the IO literature of the 1970s (Berry, 1972; Hall and Tideman, 1967, Horvath, 1972a and b; Jacquemin and Berry, 1979; Marfels, 1971a and b; Needham, 1978; Scherer, 1970; Tschoegl, 1982; Waterson, 1984). This literature has produced several prototype indices of concentration/diversification; the subsequent sections of this paper appraise them for internal consistency. The thrust of this paper is on addressing the issue of discriminatory power of current continuous measures — specifically their sensitivity to the number of diversification areas or product lines. To this effect, we examine the limit behaviour of the principal concentration indices by first showing how to calibrate them, then discussing the requisite qualities of an ideal measure, and finally providing such a measure.

Diversification (D) is the opposite of concentration (C) and could, therefore, be measured by taking the complement of an appropriate measure of concentration. Ideally, one would like to design (calibrate or ‘normalize’) both measures so that:

\[ D = 1 - C \]  

(1)

However, precisely because of this close definitional linkage, there often is confusion between direct measures of concentration and those of diversification. To distinguish between the two, this paper introduces a notation (Box) in which the measure type and the size of its domain are put in parentheses, with the letters C or D preceding the parentheses to respectively denote measurement of concentration or diversification. Thus, C(H,n) and D(H,n) denote the two uses of the HHI, as measures of product-line concentration and diversity respectively, in an n-product firm. If a measure of concentration (or diversity) takes on values ranging from 0 to 1, i.e. if it is calibrated or normalized, its complementary measure of diversity (or concentration) no longer needs to be independently computed. Between the concentration and diversity forms of a calibrated measure, complementarity will strictly hold:

\[ DC = 1 - CC \]  

(1a)

**‘Scope’ or Effect of Size**

The simplest measure of the diversity of a firm or a corporation is the number of its product lines. This simple cardinal measure of diversification totally ignores the relative share of the firm accounted for by each business or product line and may, therefore, give an incomplete picture of the firm’s diversity. *Ceteris paribus*, the larger the number of lines, the greater the cardinality or scope and the smaller the concentration.*

**‘Shape’ or Effect of Distribution**

The ‘distribution effect’ or effect of shape expresses the relative proportion of business accounted for by each area of activity. Regardless of the numbers involved, there are two identifiable extreme situations or distributions of the relative proportions of the various product lines: i) a single product line accounting for the total; ii) all areas of activity having equal shares of the total. An ideal measure should incorporate the effect of size or scope (number of product...
lines) in addition to the effect of share or shape (distribution among the components of size). Ideally, the two effects should be separately identifiable. Yet, only indirectly does this paper address the scope issue. Given the state of calibration of diversity measures in 20th century strategic research, its purpose is to pave the way for future research by calibrating the measures to account primarily for the ‘distribution’ effect.

**COMMON MEASURES OF CONCENTRATION**

**The Hirschman-Herfindahl Index (HHI)**

Commonly used by planners and regulators, the HHI is derived from the field of IO in economics. Economists (e.g., Waterson, 1984) point out that, under oligopolistic conditions, an industry’s profitability is a direct function of its concentration as expressed by the HHI.

\[ \text{HHI or } H = \sum_i p_i^2 \]  

where \( p_i \) is the share of the firm accounted for by the \( i^{th} \) product line. If the \( p_i \) denotes proportions of investments or assets, the definition of \( H \) is input-oriented; if the \( p_i \) denotes proportions of business output, the definition of \( H \) becomes output-oriented. Values of this index range from 1/n to 1, \( n \) being the number of product lines. \( H \) takes on the value 1/n when each product line represents an equal share of the total and a value of 1 when the concentration is the maximum possible, i.e., when just one product accounts for the entire output.

**The Rosenbluth Index (R)**

The Rosenbluth measure is the one advocated by IO economists (e.g., Needham, 1978). Also known as the Hall-Tideman Index (Hall and Tideman, 1967), it is defined as:

\[ R = \frac{1}{2 \sum_i p_i - 1} \]  

where the products are ranked in descending order of asset or output share, \( i \) is the rank obtained, and \( p_i \) is the proportion of the total output accounted for by the \( i^{th} \) product. The \( R \) ranges from 1/n to 1. Its interesting feature is that it weights the smaller fractions heavier than the larger ones, thus achieving a kind of balance in measuring product concentration (Waterson, 1984). Like the HHI, \( R \) is uncalibrated; it takes on the value 1 when concentration is extreme, but 1/n instead of 0 when a firm is fully diversified.

**Kwoka’s Dominance Index**

Other IO economists (e.g., Kwoka, 1977; Tschoegl, 1982) use the Kwoka’s Dominance Index. This measure emphasizes the gaps between the shares of successive products when the latter are ranked by the proportions of the firm’s assets devoted to or output accounted for by them. It is defined as:

\[ K = \sum_{i=1}^{n} (p_i - p_{i+1})^2 \]  

Kwoka’s Dominance Index ranges from 1/n^2 to 1, close enough to 0 to 1, with 0 indicating a uniform distribution of total output share among products and 1 indicating a one-product business. Though, by definition, this index takes into account a limited number of firms, the limit is high enough in most cases for the measure to be practically considered a comprehensive one. Kwoka’s Dominance Index appears at first to be an easily understood index of good practical value, but analysis reveals that its performance is poor in intermediate cases.

**Entropy Measure of Diversification**

The use of Entropy to measure diversification is not recent and its acceptance in the strategy literature is well under way. In the IO literature, the use of Entropy for measuring diversification was promoted by Jacquemin and Berry (1979). In the strategy literature, it gained acceptance following Palepu (1985). Entropy is defined by:

\[ E = - \sum_i p_i \log p_i \]  

where \( p_i \) again, is the share of the firm accounted for by the \( i^{th} \) product. \( E \) ranges from 0 to \( \log n \), where \( n \) is the number of product lines. When concentration is extreme, \( E \) takes on the value 0 and when concentration is minimal and diversification maximal, \( E \) equals \( \log n \). Contrary to the preceding indices, \( E \) is a direct measure of diversification and a problematic inverse measure of concentration.

**Internal Consistency**

A measure of concentration (diversification) should be able to give a corresponding measure of diversification (concentration). Neither one of the above three measures of concentration (i.e., the Herfindahl, Rosenbluth, and Kwoka indices) is adequate to yield a corresponding measure of diversification according to equation (1a) because neither of them strictly lies between 0 and 1. Nor does the usual Entropy function, primarily an uncali-
brated measure of diversification, readily gives a corresponding measure of concentration.

The other desired feature of a concentration/diversification measure is to capture the frequency or 'distribution' effect mentioned earlier. It should be comparable across different sizes (Adelman, 1951); in other words, the first requirement of a concentration measure should be to reflect the distribution of the firm's shares of its products, irrespective of their number. However, we show in a subsequent section of this paper that they get distorted when the total number of products increases beyond a very small number.

**Continuity Analysis of Common Continuous Measures**

It stands to reason that, for a situation midway between two limit cases, the measures should take values at worst in the middle third of their range. Figure 1 displays six gradations in distribution labelled A to F, describing six possible ‘loading’ types. They range from the extreme case of the ‘point load’ (a single firm in an industry or a single product line in a firm), to the other extreme of a uniform distribution of firms or products within a firm. The middle case is approximated by the *triangular distribution*. In this case, when proportions are ranked, they vary with regularity by a constant amount. A triangular distribution could be a partial one as depicted in Figure 1.C2 or it could provide a (linearly increasing) coverage of the entire range as in Figure 1 D.

Analyses of the Hirschman-Herfindahl, Entropy, Rosenbluth, and Kwoka indices were undertaken for point, triangular, and uniform distributions, and for increasing values of n. The analyses reveal that the existing measures do not take values in the desired range for an intermediate situation such as a triangular distribution of the firm’s shares among its products. As shown in Figure 2, the measures tend to have their values heavily skewed toward their lower limits. This constitutes a major inadequacy of the present indices: for all firms whose number of product lines is moderate or large, the concentration figure obtained is likely to be a similarly small number. In other words, as plotted in Figure 2, there is

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**Figure 1: Six Gradations In Loading Patterns (From the More Concentrated to the More Diversified)**

![Diagram showing six loading patterns: A: The "point load" (M=L), B: Load concentrated on 20% of the range (M=.9L), C1: Rectangular load spanning only 40% of the range (M=.8L), C2: Triangular load spanning 60% of the range (M=.8L), D: Triangular loading (M=.67L), E: Semi-elliptic load (M=.6L), F: Uniform loading (M=.5L).]
little or no discriminatory power to be found among the indices $C(H,n)$, $C(K,n)$ and $C(R,n)$, as well as $E$, which are all similarly low for $n > 10$ or as little as $n > 7$ for some of them. In practice, this can cause considerable distortions with potentially damaging consequences as discussed below.

**Potentially Damaging Consequences**

**Strategy Research**

As described by Davis and Duhaime (1992), the trend among database providers is towards ever-greater refinement. While early diversification studies aggregated firms at the 2- or 3-digit SIC level, contemporary studies use the 4-digit SIC level and may contemplate the new 5-digit NAIC system or even go down to the ‘segment’ level. At this level, most Fortune 500 firms are likely to exhibit ten or more product lines. Diversification studies are distorted by the fact that these diversity measures become unreliable and biased toward the high end of their range.

**Corporate Planning**

Corporate planners seldom have access to their competitors’ databases and operate with rough data. Within their own corporations, they plan for vastly different strategic business units (SBUs). Seldom would these SBUs exhibit a comparable number of product lines. Corporate planners are not currently advised on how to correct for the skewness of the measures of concentration illustrated in Figure 2.

**Governmental Regulation**

Regulatory agencies have not been made fully aware of the extent of distortion that could affect Herfindhal-based assessments of industry concentration. In this domain, where money and reputation are at stake, lack of discriminatory power of current indices (in particular, the Herfindahl index) is a simmering problem. The present regulatory fixation on the current, uncalibrated form of $H$ (Business Week, 1998) penalizes merging firms diffe-

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**Figure 2: Plot of the Herfindahl, Rosenbluth, and Kwoka Concentration Indices in Function of the Size Variable $n$**

![Figure 2: Plot of the Herfindahl, Rosenbluth, and Kwoka Concentration Indices in Function of the Size Variable $n$](image)

**Note:** The uncalibrated Entropy measure $C(E,n)$ is almost zero for $N=3$ and is defined as a measure of concentration (takes on negative values) for $n \geq 3$. For this reason, it is $CC(E,n)$ that has been plotted here. The values of $C(E,n)$ are listed in Table 1.
rentially depending on their scope or number of product lines.

**CONSTRUCTING BETTER MEASURES**

**Calibration Requirements of an Ideal Continuous Measure**

The general idea of a measure is to find a correspondence between a real-life phenomenon or variable and some mathematical scale (Ackoff, 1962; Stevens, 1946). The scale most often used is the usual (interval) scale of real numbers. We express our requirements of a continuous measure by the following four conditions:

1. The measure function must be *normalized*. In the present case, this becomes the condition that the concentration measure takes on the value 0 in the case of a fully diversified firm and 1 in the case of a fully concentrated one independent of the number of product lines (Berry, 1972).⁹

2. In addition to normalizing for the extreme cases, the measure function chosen must be a *monotonic* transformation which associates increasing values to increasing amounts of the phenomenon or event to be measured. This implies ensuring that the middle case is also adequately represented by the corresponding value of the measure (Marfels, 1971b; Waterson, 1984). We interpret this as a condition that a continuous measure function should take on values roughly in the *middle third* of its range for a triangular distribution of pᵢ shares, and thus be ‘calibrated for n.’ This relates to Adelman’s (1951) requirement that the scope n should not affect or distort the measure.

3. A good measure should possess discriminatory power; yet *not* be extra-sensitive to small changes in input data or their distribution, but be ‘robust’ with respect to them (Chatterjee and Blocher, 1992).¹⁰ Labelling rearrangements that preserve the numerical distribution of pᵢ shares should not affect the measure. In other words, it should be symmetrical and not affected by mere permutations of the pᵢ (Marfels, 1971b; Needham, 1978; Scherer, 1970; Waterson, 1984).

4. The measure should be suitable for use by practitioners. It should be easy to understand and compute. It should avoid complex mathematical expressions such as logarithms, hyperbolic functions, and all functions of e. Ideally, it should be a function of the degree to which the distribution of product lines in a firm departs from a uniform distribution.

On account of condition 4 alone, the E-function would be rejected by practitioners, in spite of Palepu’s (1985) and Raghunathan’s (1995) plea for expanding its use. Condition 4 also offers an *ex post* justification of our earlier decision not to investigate the use of some older techniques such as the Lorenz curve and the Gini-coefficient derived from it. The measure proposed in the following section is as simple to compute and use as the three principal concentration indices discussed above.

**Proposing Simple Measures: Two Alternatives**

As presented in the introductory sections, the uncalibrated Herfindahl Index C(H,n) appears to be most commonly used by practitioners while researchers increasingly use the Entropy measure D(E,n), also an uncalibrated instrument. The first reason is that Entropy is now seen by many authors as a measure that captures more than just the distribution effect (Baysinger and Hoskisson, 1989; Jacquemin and Berry, 1979; Palepu, 1985; Raghunathan, 1995; Robins and Wiersema, 1995). Quoting Palepu (1985) as a case in point:

The Jacquemin-Berry Entropy measure is based on three elements of the firm’s diversity of operations: 1) the number of product segments in which the firm operates; 2) the distribution of the firm’s total sales across the product segments; and 3) the degree of relatedness among the various product segments.

Palepu argues that both the Entropy measure and the Herfindahl Index satisfy his first two conditions, namely the ‘scope’ and ‘distribution’ effects, but believes that only the Entropy can be decomposed into two additive components:

- An unrelated component that measures the extent to which a firm’s output is distributed in products across unrelated industry group.
- A related component that measures the distribution of the output among related products within the industry groups.

This is a rather remarkable result of the decomposability of the Entropy measure known to IO economists (e.g., Waterson, 1984). It is primarily because of this property that the strategic research literature increasingly promotes the use of Entropy. The fact of the matter, however, is that recent research by Acar and Sankaran (1999) establishes that the property of decomposability is *not* the exclusive
preserve of Entropy but is shared by the Herfindahl Index as well. In other words, the current reason why strategy researchers are diverging from regulatory practice by choosing Entropy over Herfindahl may not be sound from the perspective of internal consistency. Removal of the need for decomposability highlights the importance of alternate requirements such as conditions 1 to 4 just derived. We believe that, in comparison with the very basic requirements of normalization and calibration, the property of decomposability is less imperative.

This study explores the ways of generating new concentration measures to better meet the above conditions. Since one consideration was the ease of calculation and clarity of interpretation, we chose not to use expressions involving hyperbolic, sinusoidal, exponential or other complex functions but investigated primarily the calibration of relatively simple expressions of \( p_i \) and \( 1/n \) whose calibration would be straightforward (condition 4). We, thus, propose an approach to measuring diversity with one or the other of alternative functions of the differences among \( p_i \) and \( p_j \):

\[
A_1 = \sum_{i=1}^{n} \left| p_i - \frac{1}{n} \right| \quad \text{(6)}
\]

\[
A_2 = \frac{\sum_{i=1}^{n} \sum_{j=1+i}^{n} |p_i - p_j|}{n-1} \quad \text{(7)}
\]

**Comparison of Proposed Measures and Existing Ones**

**Improvement Due to Calibration**

The advantages of the proposed alternatives are borne out on comparison with the existing measures. The first objective of this paper is to set the design requirements for acceptable measures of product-line diversity. The second objective is to describe how existing measures might be calibrated and normalized to improve measurement and allow comparing of indices. *Calibration* is the transformation that compensates for the size variable \( n \) and through which the measure can be *normalized* to take values ranging between 0 and 1. Since the extreme values of the HHI are 1/n and 1, it can be calibrated by subtracting 1/n from its value and multiplying the remainder by \( n/(n-1) \). We have also calibrated and normalized the Entropy measure by scaling it down by \( \log n \) and adjusting its sign to indicate concentration. The values attained by calibrating the existing measures for both their extreme and middle cases are illustrated in Figure 3.

Since calibrated measures, by definition, take the values of 0 and 1 respectively for uniform and point-load distributions, no differences among the measures can be revealed by these limit distributions. Only the triangular distribution provides the testing ground for comparing the indices we have retained. This is the distribution for which all the graphs appended to this article have been computed. In particular, Figure 3 shows that, even after calibration, the existing indices behave poorly in the intermediate loading case: under a triangular distribution, the Kwoka, Rosenbluth, and Herfindahl indices of concentration dip drastically for \( n > 7 \) as can be seen for the curves plotted for \( CC(K,n) \), \( CC(R,n) \) and \( CC(H,n) \). Clearly, to gain a significant improvement calibration, it becomes necessary to design inherently calibrated indices.

**Choosing among the Calibrated Indices**

H and E are still in wide use. We compare them after calibration with our proposed indices \( A_1 \) and \( A_2 \). Though the proposed alternatives \( A_1 \) and \( A_2 \) are intrinsically calibrated, we denote them here as \( CC(A1,n) \) and \( CC(A2,n) \) for the sake of consistency. Figure 4 shows the values taken by the four remaining calibrated concentration indices \( CC(E,n) \), \( CC(H,n) \), \( CC(A1,n) \) and \( CC(A2,n) \) for a triangular distribution in function of increasing values of the scope \( n \).

In the middle case of a triangular distribution, \( CC(A2,n) \) exhibits its independence of the number of product lines of a firm and maintains a value of 1/3 as graphed in Figure 4. By meeting the ‘continuity’ condition C2, \( CC(A2,n) \) presents itself as a better measure than \( CC(E,n) \) and \( CC(H,n) \). But so does our other measure, \( CC(A1,n) \). It assumes a value of 1/2 for firms with an odd number of product lines. We can prove that, for firms with an even number of products, \( CC(A1,n) \) takes a value equal to \( (1/2)*[n^2/(n^2-1)]^{1/2} \) for a triangular distribution. This approaches 1/2 as \( n \) increases.

By taking the middle value of 1/2 for a middle-case
distribution, CC(A1,n) appears to meet the continuity condition 2 better than any other measure. Does this actually mean that A1 is preferable to A2? This would be the case if the triangular distribution represented the exact middle case between the point load and uniform distribution. But, this is not exactly the case. Referring once more to Figure 1, we examine the gradation from loading pattern A (the point load) to load F (the uniform distribution).

One way to understand the underlying gradation is to use the mathematical concept of the first moment, which expresses the leverage of a probability area or a mass entering in the computations of inertias and expected values. The ‘moment’ of each loading pattern can be worked out by calculus or by using known results in solid mechanics. These moments are indicated in Figure 1 for each loading pattern. For the extreme case of a point load at the end of a span or range L, the moment is simply M=L. Next comes the load case B of the load concentrated on the extreme 20 per cent of the range; its moment is M=.9L. Next, two cases of partial loading tie with M=.8L. These are the cases of a rectangular load spanning 40 per cent of the range end (load C1) or that of a triangular load spanning 60 per cent of the range (load C2). Next comes the fully triangular load which we take as the ‘middle case’ in this research. Next comes load E representing a semi-elliptic distribution over the range with a moment M=.6L. Finally, the extreme case of the fully uniform distribution has a moment of .5L.

The triangular distribution can represent a reasonable middle ground between the point load and the uniform distribution; it is a distribution the managers may use in a strategy tilted toward either ‘growth’ or ‘value’ investments. However, it is not exactly in the middle of the first moment range which increases from M = .5L for the uniform load case F to M = L for the point load case A. The triangular pattern D, with a moment of .67L, lies a third of the way toward the uniform distribution and two-thirds of the way towards the point load. This rationale establishes that the best index is not one which would converge to a value of 1/2 for a fully triangular distribution, but one which would take the value of 1/3.
This is exactly the value of A2 irrespective of the cardinality variable n. This rationale strongly suggests that index A2 would be a better measure than all those in use at this time, since it is the one most apt at rendering properly intermediate loading patterns.

**Sensitivity Analysis on a Classical Example**

To compare the sensitivity and behaviour of these measures for distributions other than a triangular loading pattern, let us reconsider the classic example of two touchstone cases suggested by Marfels (1971b) and further stressed by Horvath (1972a). Call ‘Case A’ the case of a two-product firm, one product absorbing 90 per cent of its assets and the remaining 10 per cent being accounted for by the other product. Call ‘Case B’ the case of an eleven-product firm, one product among them accounting for 90 per cent of its assets and the remaining ten per cent equally spread among the other ten products (Horvath, 1972a). The results are summarized in Table 1.

It may be observed that the Case A firm is highly concentrated. In Case A, the Entropy measure of concentration CC(E,n) takes a value of 0.53 which does not seem commensurate with the level of firm concentration. The Herfindahl Index of concentration CC(H,n) is better than CC(E,n) insofar as it takes on a higher value, but its value of 0.64 still seems to understate the level of firm concentration. The proposed indices CC(A1,n) and CC(A2,n) take on the values 0.89 and 0.80 respectively and thus seem to make much more sense. In this one limit case, CC(A1,n) performs slightly better than CC(A2,n).

The usual assumption that a more competitive pattern is achieved once the number of firms has increased (Marfels, 1971b) is not always valid. If the increase in size two-product firm, one product absorbing 90 per cent of its assets and the remaining 10 per cent being accounted for by the other product. Call ‘Case B’ the case of an eleven-product firm, one product among them accounting for 90 per cent of its assets and the remaining ten per cent equally spread among the other ten products (Horvath, 1972a). The results are summarized in Table 1.

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The usual assumption that a more competitive pattern is achieved once the number of firms has increased (Marfels, 1971b) is not always valid. If the increase in size
is accompanied by a significant change in distribution towards greater inequality, the net result may well be a reduction in competition. Insofar as an increase in competitive activity implies a decrease in concentration, any time the challengers to the dominant firm are split up into smaller firms, the level of competition is reduced and concentration should increase. In Case B, although all four calibrated measures improve and take on reasonably high values, the absolute values as well as the per cent changes of $CC(A1,n)$ and $CC(A2,n)$ are still the most satisfactory.

It may be noted that all the concentration measures considered by Marfels (1971a), namely, the uncalibrated Herfindahl and Rosenbluth indices, the Entropy measure, and Horvath’s Comprehensive Concentration Index actually decline from Case A to Case B though the latter case is deemed to be more concentrated. This reinforces our assertion that our calibration of the Herfindahl Index results in a better measure than the original one, though definitely not quite as good as either one of our proposed measures A1 and A2.

**LIMITATIONS AND FUTURE RESEARCH DIRECTIONS**

**General Limitations of Continuous Measures**

As indicated by the methodological literature, measures are not absolute but relative to specific purposes. And, as pointed out by Nayyar (1992), there are inherent limitations on SIC-based measures due to the fact that distances between SIC codes cannot be interpreted on a ratio or interval scale. For him as for Rumelt (1974), relatedness has to be couched in terms of the key elements of input, throughput, and output characterizing each line of business. This limitation of continuous measures is well summed up by Michel and Hambrick’s (1992) statement that only Rumelt’s categories capture the degree to which relatedness may be a function of a relationship; or the degree to which it may be due to the exploitation of a common resource such as a technology, a specific production process or a particular type of expertise.

More recently, similar views are expressed by St. John and Harrison (1999) and Geringer, Tallman and Olsen (2000). Rumelt’s approach is uniquely adapted to certain uses and the introduction cites several instances of recent utilization. There are cases in which categories are preferred to continuous measures. However, Geringer, Tallman, and Olsen also point to the relative ease with which continuous measures capture curvilinear relationships. Since this study deals exclusively with the calibration of continuous measures, it does not directly shed any light on any categorical classification; only indirectly does it contribute to evaluating Rumelt’s scheme by outlining the limitations of the uncalibrated use of competing continuous measures.

**Specific Limitations of this Study**

The main concern of this paper is the distribution effect and the appropriate index calibration. The germane limitation of this study is captured by the authors concerned with the issue of spread over suitably defined market segments (Davis and Duhaime, 1992; Nayyar, 1992; St. John and Harrison, 1999). Nayyar explicitly points out that neither the scope nor the shape of diversification amounts to numerical or physical spread and cannot be revealed by mechanical examination. St. John and Harrison are concerned that the mechanical decomposition of product-line diversity [on the basis of SIC or NAICS codes, according to the procedure of Waterson (1984) and Palepu (1985)] may not reflect strategic relatedness, but be deflected instead by the hierarchical format of the SIC and NAICS classifications.

In recognition of this limitation, this research has bypassed the decomposability issue. The present research addresses another limitation of current usage. What this analysis does show is that a basic limitation has to be imposed on the use of common measures such as H and E: they ought to be properly calibrated as shown here before being used in research or regulation. Only then will they become in any way comparable to our proposed index A2. Still, the present analysis itself has its own limitations. In the first instance, it graphs computationally that extant indices are biased when the scope n increases beyond seven or ten product lines, but the paper does not provide a full theoretical justification. For reasons of space, the proofs of the invariability of A1 and A2 under a triangular distribution have been relegated to appendices not included in this printed version.

Furthermore, this study has focused primarily on the distribution effect and has not involved itself with scope or cardinality effects. Further research should attempt to take these into account without reverting back to uncalibrated H or E measures. Secondly, with a few exceptions (e.g., Chang and Thomas, 1989), the distinction is seldom made between diversity, which is a state of either concentration or spread, and diversification, which
could be seen as the strategy to achieve it.

Finally, while the product shares \( p_i \) are traditionally interpreted in output terms (sales), they could also be viewed as the proportions of input (assets, resources, etc.) accounted for by each product line. Though output may be easier to measure, a firm can have greater control over the assets it employs than over the volume of its sales. A recent paper (Acar and Sankaran, 1999) takes the position that, in view of this duality, the field could move towards habitually computing firm diversification in terms of sales as well as assets, thus affording some meaningful comparisons to researchers and strategy analysts.

**Future Directions**

In view of their satisfactory performance with respect to conditions 1 to 4, we believe that our proposed indices A1 and A2 represent an improvement over existing ones. Somewhat related to the issue of calibration is the emerging research question of whether there should be a specialization of the two most popular extant measures, the H index and the E measure. Various rationales have been advanced. First, the IO literature (e.g., Waterson, 1984) establishes that, under oligopolistic conditions, an industry’s theoretical profitability is proportional to its H-measure of concentration. Unfortunately, this computational argument is incorrect or at least incomplete in that it ignores the need for calibration. For example, in Case B of Table 1, the calibrated H measure indicates a higher industry concentration than E since the value of \( CC(H,11) \) is greater than \( CC(E,11) \). However, this example does not indicate a general trend: for instance, our computations of the middle case of the triangular load reveal that, for all values of \( n \) greater than 4, the line \( CC(E,n) \) lies above the curve \( CC(H,n) \) in Figure 4.

Second, much is made of the fact that the Entropy function is used in computer science and telephony as a measure of the amount of (binary) information transmitted. It is not clear that such a consideration is germane to the issue of product-line diversity of industry concentration.

Third, a stronger argument is often presented. As explained by Waterson (1984) and IO authors, and introduced in the strategy literature by Palepu (1985), the Entropy measure is ‘decomposable.’ Because of its presumed unique decomposability, the Entropy measure is being preferred to Herfindahl’s for measuring firm diversification, while H is sometimes limited to measuring industry structure. But, as mentioned earlier, it is coming to light that the H measure is similarly decomposable. There no longer seems to be a substantive basis for strategic researchers to espouse such limitations on their use of H and E — the more compelling limitation is the need for calibrating all continuous measures to outfit them for operation in the new century.

**CONCLUSION: ISSUES IN DEVELOPING A COMPOSITE MEASURE**

This paper has practical implications in three areas of application: strategy research, corporate planning, and governmental regulation. In the latter domain, the lack of discrimination power of current indices of concentration or diversification is becoming a problem in that limit values specified by regulations are based on biased measures. These are compounded when the Herfindahl Index becomes the sole anti-trust instrument for industry regulation (Business Week, 1998; US Department of Justice and Federal Trade Commission, 1992).

Complementing empirical investigations such as Chatterjee and Blocher’s (1992) and Hoskisson et al.’s (1993), this paper examined existing measures of industry concentration or product-line diversity on theoretical grounds and found them wanting. They should only be used with extreme care. There is a lack of calibration with respect to the effect of the cardinality or scope variable \( n \). Few Fortune 500 firms are likely to exhibit fewer than ten product lines. Diversification studies are distorted by the fact that these diversity measures of firms with several product lines become unreliable and biased towards the high end of their range. This does not hold true to the same extent for more focused firms. This differential systematic bias should ideally be taken into account when interpreting the results of published research. This paper presents clear criteria for designing diversity indices and gauging them. The use of the internally consistent and valid indices will be a definite plus for better control of sources of covariation or ‘noise’ in empirical research (Montgomery, 1982).

In addition, there is a lack of sensitivity with respect to capturing intermediate load distributions between the two extreme cases of a single firm (or product) or of a very large number of them. IO economists appear to have been suspicious of these problems for a number of years (Baker and Blumenthal, 1984; Needham, 1978; Scherer, 1970; Waterson, 1984). Yet, very little has been done to warn regulatory agencies and strategy researchers of the problems inherent in their increasing use without cali-
bration of the Herfindahl Index for industry regulation purposes and of the Entropy measure to research firm diversification, let alone to remedy the situation.

Admittedly, an ideal composite measure should incorporate both the effect of cardinality or scope and the effect of shape or distribution. Existing indices bundle these two effects; this research addresses their ‘unbundling.’ A first output of the present study is to show how present indices could be calibrated with respect to scope so as to better capture the shape or distribution effect. A second result is that two straightforward and intrinsically calibrated indices (A1 and A2) are developed. While the adoption of A2 is particularly appropriate for capturing the distribution effect of unequal shares, accounting for the influence of potentially large differences in scope (or the number of such shares) in an optimal way remains an issue for future research.

In a firm with few products, the effect of scope may be greater than that of shape. However, as the number of products increases, the marginal effect of cardinality would reduce and the effect of shape might begin to dominate. A proper assignment of weights would need to take the above into account. Alternatively, treating the scope and distribution effects as separate dimensions would be conceptually more effective but would entail operational complications, especially in regulatory applications. While the curtain is yet to fall on solving all the subtleties entailed, using the intrinsically calibrated proposed measure A2 (or even A1 in some cases) would provide a stepping stone for future progress over the next decades.

ENDNOTES

1. Practical issues pertaining to the availability and quality of data for use in strategy research are thoroughly reviewed by Davis and Duhaime (1992), Hall and St. John (1994), and St. John and Harrison (1999).

2. By the 1970s, the theoretical Industrial Organization (IO) literature in economics (e.g., Berry, 1972; Marfels, 1971a and b; Scherer, 1970) already denigrates their use in favour of continuous indices, particularly the more defensible H and E (Entropy) measures. We exclude from consideration here such measures as ‘industry concentration ratios.’ These are difficult to justify theoretically because their operational definitions only include the few largest firms or products and exclude all others. Although appealing in instances when only a few lines dominate the firm’s business, they are unsystematic and unsatisfactory (Adelman, 1951; Berry, 1972; Hall and Tideman, 1967; Marfels, 1971a and b; Needham, 1978; Scherer, 1970; Waterson, 1984).

3. The advantages of cardinal measures such as the Herfindahl and Entropy are two-fold: i) More precise modelling of the relative distribution of a firm’s business lines; ii) Lend themselves well to statistical and correlational analyses.

4. We denote a calibrated measure by a ‘C’ inserted into our general notation; for example, CC(H,n) denotes the Herfindahl Index calibrated to measure concentration while DC(H,n) denotes the calibrated diversification measure of the same H-Index.

5. Yet, the marginal effect of scope decreases with increasing size: firms with ten products diversify by ten per cent when a new line or a new business is added, but firms with 100 products would hardly feel the difference (especially if all we do is look at the mere number of lines with no regard for either their strategic or numerical importance).

6. The Entropy measure is normally expressed in terms of natural logarithms but other-base logarithms could also be used because good calibration would remove the influence of the specific base chosen — some authors do not even specify the particular log-function to use.

7. Use of the Entropy measure is greatly facilitated if it is calibrated to capture concentration directly so as not to occasionally take on negative values.

8. The real problem is not so much the scope effect or even the interaction between scope and distribution effects, but a deficiency akin to the lack of discriminatory power detected by Chatterjee and Blocher (1992) or the ‘discriminant validity’ empirically sought by Hoskisson et al. (1993).

9. Analogously, the industry concentration measure should take values ranging from 0 to 1 irrespective of the total number of firms in that industry (Hall and Tideman, 1967; Marfels, 1971b; Waterson, 1984). This seemingly minimal criterion sheds a negative light on the increasing use of Entropy without calibration as a replacement for the HHI by strategy researchers.

10. This is a primarily theoretical requirement, one not altogether unrelated to the empirical notion of ‘reliability’ sought by Hoskisson et al. (1993). One of the reasons for the popularity of the current Herfindahl Index with regulatory agencies is its sensitivity to small changes from distributions involving very high concentration (Scherer, 1970). A good index should possess a fair degree of resolution everywhere within its range.

11. The same point could be made of the current NAICS classification adopted by the US, Canada, and Mexico.

12. However, interesting follow-up studies could be undertaken in the Indian context, for instance, on such databases as Capital-Line and Prowess, to investigate the number of Indian firms diversified beyond seven to ten product lines.

13. The strategy literature is rather silent on this issue, even though managerial practice leans in favour of
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*The earth has grown old with its burden of care  
But at Christmas it always is young,  
The heart of the jewel burns lustrous and fair  
And its soul full of music breaks the air,  
When the song of angels is sung.*

*Phillips Brooks*