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ENTROPY AND OTHER MEASURES OF INDUSTRIAL DIVERSIFICATION

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Abstract

This study demonstrates that entropy is a useful measure for comparing industrial diversity either among regions or for a particular region over time. This measure allows not only examination of changes in diversity over time, but also, through its decomposition properties, an analysis of the nature of such changes.

For the purpose of illustration, employment diversity indices were computed using the entropy method for the state of Oregon from 1972 to 1984. The entropy measure was disaggregated into its between-set and within-set elements to express the extent and pattern of dispersal between and within different groups of industries.

I. INTRODUCTION

One of the major outcomes of the depression of the 1930s was a drive toward diversification of industrial activity in many areas of this country. Diversification became an important policy consideration because of the belief that specialization was a dangerous liability that could lead to periodic high unemployment and instability of income [28].

The suggested disadvantages of specialization are that a region's market for its specialty may be undercut by the discovery of new and cheaper supply sources, by improvements in production elsewhere, by improvements in transportation, or by shifts in demand.

It also is suggested that the less specialized an area is (i.e., the greater the degree to which it is diversified), the greater its ability will be to cushion adverse cyclical effects. This view is related to the widely held assumption that economic diversity enhances economic performance, the latter being measured by growth rate, per capita income, unemployment rate, or other indicators.

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For years, economic planners have assumed that diversification in the economic activity of a region increases the aggregate level of regional income or income per capita, reduces unemployment rates, increases growth rates, and stabilizes (in the sense of reducing fluctuations over time) the levels of aggregate income, employment, or other regional economic characteristics [9].

This paper will not address the debate regarding the pros and cons of different types of diversification strategies. Instead, the goal is to consider entropy for measuring industrial diversity either among the regions or for a particular region over time. For purposes of illustration, the entropy measure is used to calculate employment-based diversity for the state of Oregon.

II. MEASUREMENT OF DIVERSITY

The earliest diversity measurement was attempted by MacLaughlin in 1930. He tested the strength of relationship between the degree of industrial concentration in a given city and the severity of the cyclical, as well as the seasonal, economic fluctuations that the city experienced. His concentration measure was percent of value added by manufacture concentrated in the first five industries in each city [24]. Since his work, economists and regional scientists have developed several ways of measuring diversity: the ogive approach, the national average approach, the portfolio theoretic approach, and the information theoretic (entropy) approach.

A common index of diversity is the ogive index, which measures the deviation from equal distribution of employment in all sectors [37, 28, 4, 32, 14, 1].

Consider a set of n industrial classes, and let P_i ($i = 1, 2, 3, \ldots n$) denote the percent of employment in the ith industry class. Then the concentration index, (C), is computed by

$$C(P_1, P_2, \ldots, P_n) = n \sum_{i=1}^{n} (P_i - 1/n)^2$$

The minimum value of C (namely, zero) is attained when employment is distributed equally among industries.

Tress constructed an index of diversity for England and Wales based on 1931 employment in 12 industrial classes (basically, 1-digit SIC). Rodgers

effectively used a nearly identical technique to calculate the diversity indices of 93 standard metropolitan areas of the U.S. based on 1950 employment percentages of 22 manufacturing groups. Several years later, Conkling [4] calculated the diversity indices on three area levels: national (the island of Great Britain), regional (South Wales and Monmouthshire), local (52 employment exchange areas) for the years 1931, 1951, and for each year from 1949 through 1959. He then studied the factors associated with changes in employment diversity in South Wales, Great Britain.

The national average approach uses the national average employment or value-added figures in each industry as the benchmark for the measurement of employment diversity [11, 3, 1].

Consider a set of n industrial classes where P_i is as defined above, M_i is the national average employment in the ith industry, and α is the power to which deviations will be raised ($\alpha = 1$ for Florence, $\alpha = 2$ for Borts). The concentration index (C) is given by

$$C(P_1, P_2, \ldots, P_n) = \sum_{i=1}^{n} (P_i - M_i)^{\alpha}/M_i$$

Sargent Florence [11] used this equation to calculate the diversity indices of each state in the U.S. Borts [3] also used the national percentage distribution of employment among industries as a norm. As noted by Conroy [9], Borts studied the relationship between relative state employment fluctuations for three periods of business contraction and expansion during 1919 to 1953 and the respective industrial structure of 33 states.

In the national average method, maximum diversity consists of duplicating the national average. It may be, however, that by some criterion, a given area has a better industrial mix than the nation as a whole. In this case, movement toward duplicating the national distribution may worsen the area's stability or rate of growth. The national average measure also suffers from the difficulty that the norm (national average) is not fixed, so changes in this measure over time will not distinguish between changes in the region and changes in the nation.

In the recent past, portfolio theory has played an important role in the area of financial asset selection [26, 25, 36, 31]. The concept of diversified investment portfolios was first introduced by Markowitz [25, 26] to the process of stock selection for investors. His aim was to provide maximum return with minimum variance of return. Based largely on this concept, a new method of measuring industrial diversity, namely the portfolio theoretic approach, emerged [5, 6, 2, 29]. Michael E. Conroy was the first to employ this technique to examine the effect of industrial diversification on the stability of a region's employment [7, 8, 10]. According to Conroy, every region expects a stream of returns (employment, income, or a weighted subset of these) from investment of factor resources in individual industries. These expected returns are considered stochastic returns whose variance may serve as a measure of the fluctuation or risk. An aggregate measure of risk that may be associated with the industrial structure of a region is called portfolio variance and is defined in terms of the present notation as:

$$\sigma_p^2(P_1, P_2, \ldots, P_n) = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i \, P_j \, \sigma_{ij}$$

where p as subscript means portfolio and P_i and P_j are the percent of regional resources (employment, income, or outputs) allocated to industries i and j and where σ_{ij} denotes the covariance of these resources (employment, income, etc.) over time for the ith and jth industries.

The covariances are calculated as follows. Denoting E_{it} as employment (or income, etc.) in the ith industry in period t, the annual growth rate of employment can be expressed as:

$$G_{it} = (E_{it} - E_{it-1})/E_{it}$$

Assuming that the growth rate is a stochastic stream of returns drawn from some probability distribution, the mean and covariance can be derived as:

$$\hat{\mu}_i = 1/n \sum_{t=1}^{n} G_{it}$$

$$\sigma_{ij} = 1/(n-2) \sum_{t=1}^{n} (G_{it} - \hat{\mu}_i)(G_{jt} - \hat{\mu}_j)$$

Industrial diversification using the portfolio approach would involve the explicit attempt by a region to reduce fluctuations (instability) in the aggregate returns to the region from its portfolio of investment. The portfolio measure measures not only the individual instability of a given industry but also the degree to which its fluctuations are correlated with the fluctuations of other industries. The measure is only indirectly (presumably inversely)

related to diversity, in the sense that diversity is measured by the ogive, national average, or entropy indices.

Barth [2] applied the portfolio theoretic technique to investigate the relationship between the industrial mix and employment stability for nine industries in Virginia during the years 1951 to 1971. Using Conroy's portfolio variance formula, Barth found that "the estimate of employment risk decreased from 7.3 percent in 1952 to 7.08 percent in 1971, a 4.1 percent reduction in risk" [2].

The Conroy method (portfolio variance) suffers from at least one shortcoming. This has to do with Conroy's argument that the smaller the variance, the more stable the region. The use of variance as a norm, however, is not a good measure of diversification—it is not conceptually consistent with the intuitive notion of diversification in the absence of concentration. St. Louis echoes this criticism:

> A region might well have an industrial mix that is associated with a growth rate in employment sufficiently rapid to compensate for a relatively large variance in employment. And a region with a small variance could have a zero or even negative growth rate. [29]

Entropy as a measure of disorder, uncertainty, or homogeneity has been used to analyze many different phenomena. In the physical sciences, it has been used to measure the irreversible increase of unavailable energy. In the biological and behavioral sciences, entropy has been used as a measure of disorganization. In communication theory, it quantifies the degree of uncertainty in a system [30]. Taking the Shannon entropy as a measure of diversity yields

$$D(P_1, P_2, \ldots, P_n) = -\sum_{i=1}^{n} P_i \log_2 P_i$$

In the context of communication theory (where this measure gives the uncertainty H), P_i is the probability of some event i. As a measure of diversity, P_i represents the proportion of some total quantity. For example, let K denote some quantity such as total employment, total output, foreign trade, or income and K_i the amount contributed to this total by the ith entity, such as an industry in a region, a county, or a product traded. The value shares are $P_i = K_i/K$ and the entropy measure gives the diversity or spread of the distribution [17]. The maximum value of D is attained ($\log_2 n$) when all P_i

are equal. If the ith entity is the only contributor to K, then $P_i = 1$, all other $P_i = 0$, and D = 0.

The entropy measure has been invoked in empirical studies in economics as well as management, marketing, finance, and accounting. In a marketing context, entropy can represent the distribution of consumer preferences for various brands. For example, Herniter [16] uses entropy as a measure of uncertainty or disorder in the stochastic system that represents the consumer's preferences for special brands.

In the analysis of empirical data, entropy also has been used as a measure of dispersion, an alternative to the variance σ^2 (a measure of risk or uncertainty). For example, the use of entropy rather than variance as a measure of the risk of a securities portfolio whose components yield stochastic returns has been advocated by Philippatos and Wilson [27]. They concluded that since entropy can be estimated directly from variances (when the form of prior distribution is known) and can be computed from nonmetric data, entropy is more general and better suited for the selection of portfolio than variance.

In the analysis of accounting data, entropy has been used to measure the loss of information from aggregation of items on financial statements, e.g., the balance sheet [34, 22, 23].

An extensive treatment of entropy-based measures in the analysis of economic data has been given by Theil [33], who discusses in detail the basic technical informational concepts and illustrates them with economic examples. Theil [33, 35] primarily is concerned with distributional issues and with decomposition analysis. In particular, he has argued that information concepts provide an appropriate measure that can be utilized in empirical studies in economics to answer such questions as: how is income distributed among the families of a nation or among the states of a nation? How are sales, total outputs, or employment distributed among industries within a region and among regions? How is international trade distributed among countries?

In market structure analysis, entropy has been employed as a measure of competitiveness of an industry [18]. Here P_i represents the market shares of firms in the industry. As such, entropy varies inversely with the degree of industrial concentration. Using this measure, Horowitz and Horo-

witz [18] analyzed the concentration in the brewing industry between 1944 and 1964.

Using the decomposition property of entropy, some market structure researchers were able to analyze concentration either within or between regions, or within brands of an individual company, and between companies [21, 19, 33]. For example, Horowitz and Horowitz [20] studied the source of industrial concentration (i.e., concentration within all regions versus concentration within a particular dominant region) in 21 2-digit manufacturing industries in the common market nations. Jacquemin and Berry [21] combined the sales data for the 460 4-digit U.S. largest industrial corporations of 1960 and 1965 into separate 2-digit industry groups. The entropy measure was calculated for: (a) across 2-digit industry groups; (b) across 4-digit industry groups; and (c) within 2-digit industry groups. They concluded that some corporate diversification at the 4-digit level is a consequence of diversification at the 2-digit level.

Along similar lines, Garrison and Paulson [13] used entropy and a related measure to test the hypothesis that labor-intensive industries are less concentrated geographically than other types of industries. The results of the study support the hypothesis.

Entropy measures of geographical concentration also have been used by Garrison [12] to examine the extent to which rural and small-town counties compete with urban areas for manufacturing employment in the Tennessee Valley region. Here P_i represents the relative ability of the ith county to attract manufacturing industries. Decomposition of entropy into its between-set and within-set components also has enabled Garrison to compare the low wage and high wage industries of the region as to the nature of their geographical dispersal over time.

Entropy also has been used to measure employment diversity by Hackbart and Anderson [15]. Within this context, the P_i represents the ith sector share of regional employment. Hackbart and Anderson illustrated the applicability of the entropy method by examining four river basin regions in Wyoming. They concluded that the entropy method "provides a direct means of comparing diversity in different regions or changes in diversity over time" [15]. They did not examine how their measure of diversity can be decomposed, however, so that various patterns of interindustry diversification within a region over time may be examined.

The entropy measure is a more flexible and analytically powerful measure of economic diversity than the national average measure. The uniform distribution of economic activities used as a comparative norm for the entropy measure is more objective and conceptually consistent with the intuitive notion of diversification as the absence of concentration than the comparative norm of some other (national) distribution.

The national average measure assesses the deviation of the regional distribution of economic activity from the national distribution. The use of a national pattern as a norm is questionable, however, because it implicity suggests that the region deny itself its own comparative advantage. Also, since the national distribution changes over time, this measure does not determine whether the distribution of economic activity within a region itself has become more or less diversified over time. Because the uniform distribution is a comparative norm that is fixed, the entropy measure will accomplish the above objectives.

The ogive and entropy measures are conceptually similar, as both approaches compare actual distribution of employment to a hypothetical uniform distribution representing balanced industrial composition (equal percentage in each group). The entropy measure is more flexible than the ogive, however, as the entropy measure can be decomposed so that the various patterns of interindustry diversification within a region over time may be examined. These patterns and changes may not be apparent from an examination of the single unit total diversity index of diversification. As discussed earlier in this section, the decomposition property has permitted some useful extensions of regional analysis and market structure analysis by enabling researchers to analyze concentration and structural changes both within and between regions. The following section illustrates the manner in which the entropy measure can be decomposed to express the extent and patterns of diversification between and within manufacturing and nonmanufacturing sectors for the state of Oregon.

III. DECOMPOSITION OF THE ENTROPY MEASURE

The entropy method as applied to employment data measures diversity of a region against a uniform distribution of employment in all sectors. As discussed above, the entropy measure of industrial diversity is given by:

$$(1)\quad D(E_1, E_2, \ldots, E_n) = -\sum_{i=1}^{n} E_i \log_2 E_i$$

Where n = the number of economic sectors, and

E_i = the proportion of total employment of the region that is located in the ith sector.

This entropy measure can be disaggregated into its between-set and within-set aspects to express the extent and pattern of dispersal between and within different groups or subsets of industries. Consider, for example, that industries (sectors) are grouped into G sets. The employment share of set S_g is then

$$E_g = \sum_{i \epsilon S_g} E_i \qquad g = 1, \ldots, G$$

The entropy index of diversity within a particular set, S_g, can be measured by:

$$(2)\quad D_{\text{within } S_g} = -\sum_{i \epsilon S_g} (E_i/E_g) \log_2 (E_i/E_g)$$

Weighting this expression by E_g/E_s, which is the relative share of each set of the G sets, yields:

$$(3)\quad D_{\text{within}} = \sum_{g=1}^{G} (E_g/E_s) \left[-\sum_{i \epsilon S_g} (E_i/E_g) \log_2 (E_i/E_g) \right],$$

which is the average diversity within the G sets.

The between-set measure represents the application of the entropy measure to the G different groups of industries treated independently, as is given by:

$$(4)\quad D_{\text{between}} = -\sum_{g=1}^{G} E_g/E_s \log_2 E_g/E_s$$

The between-set measure identifies the extent to which employment is distributed equally between the G sets.

The overall entropy measure can be obtained by summing equations 3 and 4:

$$(5)\ D = -\sum_{g=1}^{G} (E_g/E_s)\log_2(E_g/E_s) + \sum_{g=1}^{G} (E_g/E_s)[-\sum_{i \in S_g} (E_i/E_g)\ \log_2\ (E_i/E_g)]$$

In the following section, this disaggregation of entropy into its between-set and within-set aspects, where G = 2 (manufacturing and non-manufacturing), is carried out for the state of Oregon and its results are presented in the following section.

IV. ENTROPY MEASURE: AN ILLUSTRATION

The interest in economic diversification is a nationwide phenomenon, but it has been felt particularly in Oregon during the 1970s. Many of Oregon's 36 counties rely heavily on the timber industry, which provides 80,000 jobs throughout the state. In 1980, the lumber and wood product industries employed one out of three workers in several Oregon counties such as Crook, Harney, Grant, and Lake. Although there has been a significant movement away from dependence on the lumber and wood products industry, it has nonetheless continued to dominate the manufacturing sector. Lumber and wood products account for virtually the entire economic base of many of the state's counties. Most of the economic transition in Oregon has been concentrated in the metropolitan areas of Portland and Salem. Over 60 percent of the nonforest and food products employment is located there, with the balance of the state for the most part still subjected to the unpleasant side effects of slow-growing, highly seasonal, and cyclical industries.

An important aspect of the problem of diversity concerns whether there is a tendency toward greater diversity as an area matures. To examine the changes in diversity over time, the diversity indices of employment data were calculated for Oregon for the thirteen year period from 1972 to 1984. Calculation of the entropy measure for Oregon is based on employment data from 41 sectors (2-digit SIC). The value, E_i, which measures the ith sector's relative share of employment for a given year, is calculated from Oregon resident labor force data provided by the State of Oregon, Employment Division, Department of Human Resources.

Since there are 41 sectors, the maximum value is:

$$D(E_1, E_2, \ldots, E_9) = \log_2 41 = 5.358,$$

The diversification values would range from 0 to 5.358, with a diversification value of 5.358 denoting the greatest diversification among the 41 sectors of a county.

Table I presents the calculated diversity indices of employment data for Oregon for the thirteen year period. There is some evidence in these results of a slight trend toward greater industry concentration in the overall Oregon economy. This single unit total entropy measure, however, does not identify interindustry diversification or concentration patterns and structural changes occurring within the entire economy. The entropy measure can be disaggregated into its between-set and within-set elements to express the extent and patterns of dispersal between and within different groups of industries. The following section presents the results of this disaggregation analysis.

The 41 economic sectors of Oregon were combined into two separate groups, where S_1 is defined as manufacturing (19 sectors) and S_2 as nonmanufacturing (the remaining 22 sectors).

TABLE I
Employment Diversification Indices for Oregon

Year	Diversity Index
1972	4.641
1973	4.651
1974	4.648
1975	4.618
1976	4.608
1977	4.609
1978	4.605
1979	4.617
1980	4.617
1981	4.601
1982	4.591
1983	4.572
1984	4.574

The disaggregation of entropy for the above two groups was carried out and the results are presented in Table II, columns (2) through (9). The aggregated employment diversification indices initially presented in Table I are shown in column (10).

The within-set component of the entropy measures for the manufacturing and nonmanufacturing groups produced from applying equation 2 is presented in columns (2) and (3), respectively. The within-set measure represents the application of the entropy measure to the two industry groups treated independently. There is some possible evidence in column (2) of a trend toward greater diversification within the manufacturing set and in column (3) of a trend toward increasing concentration within the nonmanufacturing set.

Greater diversification within the manufacturing set in Oregon was obtained by a significant movement away from dependence on the traditional resource-oriented industries of food and forest products. Lumber and wood products, as well as food products, grew at a relatively slow pace during the thirteen year period, falling from a combined total of 54.7 percent to 44.7 percent of the total manufacturing employment.

Paper and allied products, while stable employers, have shown a small steady decline. The industrial pacesetters during this period have been the high technology industries, consisting of machinery, electrical equipment and supplies, and instruments and related products. The high technology sector has increased its employment from 12.5 percent of total manufacturing to 22.1 percent between 1972 and 1984. Total employment in this sector increased by 91.3 percent from 23,000 in 1972 to 44,000 in 1984.

The weighted within-set entropy measures of the manufacturing and nonmanufacturing groups produced from applying equation 3 are presented in columns (5) and (7). These two columns are obtained by multiplying the two sets' relative share of employment (column (4) and (6)) by the within-set entropy measures of column (2) and (3) respectively. The weighted within-set measure represents each group's contribution to the degree of economic diversification within the total economy. Results in column (5) suggest a very slight trend toward decreasing contribution of manufacturing to the degree of economic diversification. That is, even though diversity in manufacturing was increasing, the decrease in percentage of manufacturing more than neutralized this effect. Column (7) suggests a very slight trend toward greater contribution

TABLE II
A Disaggregated Entropy Measure of Employment Diversity
Oregon, 1972–1984

Year	Within-Set Entropy Mfg.	Within-Set Entropy Nonmfg.	% Share Mfg.	Weighted Within-Set Entropy Mfg.	% Share Nonmfg.	Weighted Within-Set Entropy Nonmfg.	Total Weighted Within-Set Entropy	Between-Set Entropy	Total Entropy
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1972	3.100	4.095	.226	.700	.774	3.170	3.870	.771	4.641
1973	3.139	4.093	.230	.722	.770	3.151	3.873	.778	4.651
1974	3.194	4.078	.224	.717	.775	3.162	3.879	.768	4.648
1975	3.212	4.055	.208	.669	.792	3.211	3.880	.738	4.618
1976	3.185	4.045	.212	.675	.788	3.188	3.863	.745	4.608
1977	3.210	4.040	.212	.680	.788	3.183	3.864	.745	4.609
1978	3.244	4.029	.210	.680	.790	3.184	3.864	.741	4.605
1979	3.297	4.030	.209	.690	.791	3.186	3.876	.740	4.617
1980	3.378	4.026	.199	.672	.801	3.225	3.897	.720	4.617
1981	3.391	4.014	.192	.652	.808	3.242	3.894	.706	4.601
1982	3.418	4.006	.187	.638	.813	3.258	3.896	.694	4.591
1983	3.346	3.995	.189	.633	.811	3.239	3.872	.699	4.572
1984	3.360	3.989	.192	.644	.808	3.224	3.868	.705	4.573

of nonmanufacturing to the degree of economic diversification. That is, even though diversity in nonmanufacturing was decreasing, the increase in percentage of nonmanufacturing more than neutralizes this effect, given the higher diversity of the nonmanufacturing sectors. The weighted within-set components of the entropy measures for the manufacturing and nonmanufacturing groups are summed to yield the total weighted within-set entropy measure shown in column (8). There is no evidence of any trend revealed by the total weighted within-set entropy measure, i.e., joining manufacturing and nonmanufacturing together obscures the changes that have happened within each set.

The between-set entropy measure that results from applying equation 4 is presented in column (9). The between-set measure identifies the extent to which Oregon's employment is distributed equally between the manufacturing and nonmanufacturing sets. There is some possible evidence of a trend toward greater between-set concentration over the thirteen year period. The percentage employment shares of the two groups are shown in columns (4) and (6). In 1972, the percentage employment shares of manufacturing and nonmanufacturing were about 23 percent and 77 percent, respectively. During the rest of the study period, the manufacturing percentage share generally decreased, while the nonmanufacturing percentage share generally increased (i.e., the distribution of employment in these two groups became more disparate). This accounts for the decrease in between-set entropy (i.e., the greater concentration of the Oregon economy in one of the two aggregated sets). By comparison, the total weighted within-set entropy shows no clear trend. Thus, a concentration appears to have occurred between the industry groups rather than within them.

The total weighted within-set measure is added to the between-set measure to yield the total entropy measure as formulated by equation 5. (This is the same as the aggregated entropy measure of industry diversification initially presented in Table I).

As discussed earlier, there is some possible evidence in column (3) of a trend toward increasing industry concentration within the nonmanufacturing group. Column (7) also suggests evidence of a trend toward greater contribution of nonmanufacturing to the degree of economic diversification within the total economy. But this contribution is balanced by the reduced contribution of manufacturing to diversification within the economy, as shown in column (5). The net (total weighted) within-set entropy, given in column (8),

shows little change. By contrast, the increasing between-set concentration toward nonmanufacturing and away from manufacturing shown in column (9) is clear. Its consequences are greater concentration and less diversification in the total economy. These findings highlight the value of decomposing the entropy measure in order to be able to interpret the structural changes occurring within the economy.

IV. CONCLUSIONS

The proposed entropy measure provides a flexible and analytically powerful measure of industrial diversity. This measure is capable of providing a single index of diversification that takes into account all the industrial sectors in the region. It provides a precise definition of economic diversity that can be used as a means of comparing changes in diversity over time and also, through its decomposition properties, of evaluating the nature of such changes.

This technique was used to calculate the changes in diversity over the 1972 to 1984 period for Oregon. Furthermore, the decomposition of entropy into its within-set and between-set aspects permitted the analysis of the exact nature and extent of tendencies toward diversification or concentration between and within manufacturing and nonmanufacturing industries.

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