The Measurement Of Spatial Association[#]

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Location theory assumes that the firm attempts to select a profit maximizing location. Generally, a profit maximizing location will be somewhere in the space bounded by the sites of the firm's inputs and markets. When transportation costs for one input or to one market are sufficiently large relative to others, however, such costs may so dominate all others as to make the profit maximizing location adjacent to the particular input or market site. In such cases a firm is said to be "oriented" to the particular input or market. Inputs, including raw materials, labor, energy, transportation, and agglomerative economies, and markets are collectively referred to as factors of location. Thus, firms in some industries are described as having "factor orientations," which simply means that their profit maximizing locations tend to be near the sites of the firms or households supplying the dominant factor.

For public policy purposes such as industrial development, knowledge of the orientation of firms is quite useful. The empirical identification of orientation is not as straightforward as the discussion above implies because all firms in a given industry are not subject to identical locational forces. Transportation costs, demand and noneconomic variables such as satisficing behavior and inertia may produce a spatial pattern in which only some firms in an industry exhibit a factor orientation. The non-homogeneous nature of firms within "industries" identified in aggregate data makes it even less likely that all firms in such industries will exhibit identical locational orientation.

A procedure frequently used for estimating the extent to which firms in an industry are oriented to a locational factor is to measure the degree to which the firms tend to locate near, or associate themselves with, the sites of firms supplying the raw materials, other inputs, markets or agglomerative economies.

In this paper various measures of pairwise geographic association are analyzed and compared.¹ The coefficient of correlation calculated between regional distributions of industrial employment is tentatively concluded to be the most satisfactory measure of geographic association among those considered. This measure is then applied to disaggregated data for selected U. S. manufacturing industries.

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Measures Based on Distances

Ideally, a measure of geographic association should reflect the response to an orientation factor, existing in the form of establishments in one industry, by establishments in a second industry. Because locational data from a single point in time cannot be used to distinguish which industry is producing the response and which is the respondent, associations are frequently measured without regard to which industry is the respondent.

Attempts to measure geographic associations between firms in different industries may be divided into two basic types: (1) those which make use of the actual distances of establishments in one industry from the establishments in a second industry that provide inputs, markets or agglomerative economies to establishments in the first industry, and (2) those which make use of the relative spatial distribution of establishments in the two industries without explicit reference to any distance measures. The second type will be discussed in the following sections of this paper. An example of the first type is provided by Hale [7] who used mean shipment distance of all raw materials and components and the mean distance of final products as measures of concentration or association. Unfortunately, the mean shipment distances that he used contain little evidence of geographic associations corresponding to the notion of orientation to a factor of location as described above (all of the mean distances reported by Hale are greater than 200 miles).

The use of mean distances as measures of association can be criticized because of several additional shortcomings. The use of such mean distance measures makes it unlikely that even a very close geographic association between two industries will be detected because all distances for inputs or outputs of all the industries' suppliers and purchasers are averaged together. The 1963 input-output study of the U. S. showed, at the 363-sector level of disaggregation, that the average manufacturing sector had its inputs supplied by firms in 94.77 different sectors and sold its output to firms in 69.52 different sectors^{2,3} [20] [12]. The magnitudes of these numbers seem to assure that a strong association between one industry and a second will not be detected using mean distances because a strong association, represented by a short distance, will be overwhelmed in calculating the mean by a large number of longer distances. In addition, the use of average distances can be misleading even for a single pair of detailed industries that are closely associated. For example, if firms in the two industries locate in the same region (shipment distance assumed = 0) five times and if the two are 1200 miles apart in a sixth instance, the mean shipment distance between the two would be 200 miles. From this perspective the median distance might provide a better measure.

The preceding findings indicate that a better measure of association would not average all the input suppliers and output purchasers for an industry together, and might make use of the whole distribution of ship-

ment distances (not only the mean of the distribution). Unfortunately, shipment distances data of the sort needed are not readily available and, even if they were, appropriate ways for utilizing the whole distribution of distances have not yet been developed. Therefore, a number of measures of geographic associations have been developed which make use of the regional distribution of activities without requiring any knowledge of the actual distances between the establishments or regions. All such measures assume that intra-regional distances are small enough to be ignored. In the following section, employment is used as the indicator of each industry's level of activity because employment data are more readily available than other indicators such as income or output and because employment has been shown to correlate highly with those indicators [16].

Dichotomous Measures of Relative Location

A simple way of describing the regional distribution of an industry's activity is to assign a value of 1 for any region in which there is activity and a 0 to those in which there is none. Artle [1] used this approach but was concerned primarily with intra-industry associations or the degree of concentration (localization) of firms within a single industry rather than the degree of geographic association between firms in different industries. Ratcliff [17] measured the degree of association between pairs of industries by comparing the number of regions within which both the first and the second industries are located with the number in which only one of the industries is located. There are different measures of association for each pair of industries, with one or the other industry serving as the comparative base (see Table 1). These measures are testable, but it is unclear which should be used under what conditions. Czamanski [4] also made use of the numbers of regions in which each activity is located. His measure of association is a value of chi-square for each pair of industries calculated as indicated in Table 1. A distinct disadvantage of both Ratcliff's and Czamanski's measures is that they do not make use of information regarding the level of an industry's activity, such as the level of employment in each region. Simply using the presence or absence of the activity becomes an especially questionable practice with large regions and/or highly aggregated data, because in such cases most regions will contain most industries. This is not a problem if use is made of regional variations in the level of each industry's activity. It is to measures that make use of these variations that we now turn.

Continuous Measures of Relative Location⁴

P. Sargent Florence [6] developed a coefficient of geographic association, G_{ki} , which corrects for the major defects of the measure described above. Its calculation is shown in Table 1. This measure was severely criticized by Kendall [9], McCarty, *et al.* [15], and Richter [18]. The

TABLE 1. Measures of Geographic Association

Ratcliff:

$$A_{kl}/B_{kl}, \text{ or } A_{kl}/C_{kl}$$

Czamaniński:

$$\chi^2_{kl} = \frac{(A_{kl}D_{kl} - B_{kl}C_{kl})^2 N_{kl}}{(A_{kl} + B_{kl})(C_{kl} + D_{kl})(A_{kl} + C_{kl})(B_{kl} + D_{kl})}$$

Florence:

$$G_{kl} = \sum_j \left| \frac{X_{kj} - X_{kl}}{X_k - X_l} \right|$$

Richter:

$$R'_{kl} = \frac{\sum_j \left(\frac{X_{kj}}{P_j} - \frac{X_{lj}}{P_j} \right) - \left(\sum_j \frac{X_{kj}}{P_j} - \sum_j \frac{X_{lj}}{P_j} \right)}{\sqrt{\left[N_{kl} \sum_j \left(\frac{X_{kj}}{P_j} \right)^2 - \left(\sum_j \frac{X_{kj}}{P_j} \right)^2 \right] \left[N_{lj} \sum_j \left(\frac{X_{lj}}{P_j} \right)^2 - \left(\sum_j \frac{X_{lj}}{P_j} \right)^2 \right]}}$$

McCarty, *et al.*:

$$R_{kl} = \frac{N_{kl} \sum_j X_{kj} X_{lj} - X_k X_l}{\sqrt{\left[N_{kl} \sum_j X_{kj}^2 - (X_k)^2 \right] \left[N_{kl} \sum_j X_{lj}^2 - (X_l)^2 \right]}}$$

Adjusted R_{kl} :

$$R^* = \frac{N^*_{kl} \sum_j X_{kj} X_{lj} - X_k X_l}{\sqrt{\left[N^*_{kl} \sum_j X_{kj}^2 - (X_k)^2 \right] \left[N^*_{kl} \sum_j X_{lj}^2 - (X_l)^2 \right]}}$$

where:

X_{ij} = employment in industry i in region j ,

$X_{i.} = \sum_j X_{ij}$ = total employment in industry i ,

$X_{.j} = \sum_i X_{ij}$ = total employment in region j ,

P_j = population in region j ,

A_{kl} = number of regions for which $X_{kj} > 0$ and $X_{lj} > 0$,

B_{kl} = number of regions for which $X_{kj} > 0$ and $X_{lj} = 0$,

C_{kl} = number of regions for which $X_{kj} = 0$ and $X_{lj} > 0$,

D_{kl} = number of regions for which $X_{kj} = 0$ and $X_{lj} = 0$,

$N_{kl} = A_{kl} + B_{kl} + C_{kl} + D_{kl}$, and

$N^*_{kl} = A_{kl} + B_{kl} + C_{kl}$.

criticisms noted that the coefficient is affected by the absolute sizes of the employment figures so that equal-sized increases in a single industry's employment in all regions would alter the measure of its association with every other industry. Furthermore, the fact that the distribution of G_{kl} has not been specified makes significance tests of its value impossible.

Because of these criticisms, McCarty, *et al.* [15] proposed the coefficient of correlation, R , between two industries' regional employment distributions as the appropriate measure of their geographic association (see Table 1). This coefficient was criticized by Richter [18] on two grounds. First, the regions used by McCarty, *et al.* were large political areas. This is obviously not a valid criticism of the measure itself but of the data base used to test the performance of the measure. Second, Richter noted correctly that the measure would be high *if* there is a high correlation between each industry's regional employment distribution and the regional distribution of population (two variables each correlated with the same third variable will be correlated with each other). Note that this result occurs only when there is a high correlation between employment and population. There will be such high correlations for most industries when the regions are large and the industries are highly aggregated, as in McCarty, *et al.* or Richter, but this is, once again, a function of the data set and not of the measure. When the data consist of 4-digit SIC manufacturing industries and the regions are a set of SMSA's and non-SMSA areas spanning the United States, correlations between population and regional employment are not uniformly high (see Table 2). Consequently, the correlation coefficient as the measure of association need not be uniformly large. In those cases in which both industries are highly correlated with population, the measure of association is appropriately high,

TABLE 2. Frequency Distribution for Correlation Coefficients Between Regional Employment and Population Distributions^a

Value of Coefficient of Correlation	Cumulative Frequency (%)
> .900	1.5
.800 — .899	8.0
.700 — .799	17.5
.600 — .699	24.5
.500 — .599	33.5
.400 — .499	51.0
.300 — .399	60.0
.200 — .299	72.5
.100 — .199	85.5
< .100	100.0

a. Based on 1960 population and 1963 estimated figures for 199 4-digit SIC industries in 193 Standard Metropolitan Statistical Areas (SMSA's), 12 State Economic Areas in New England, and 172 Bureau of Economic Analysis regions excluding the SMSA's and SEA's.

however. Note that the objective is to measure or describe geographic association and not to explain it.⁵

To avoid the problem of upward bias because of mutually high correlations with population in his data, Richter used regional population to deflate the regional employment figures to be correlated (see Table 1). Unfortunately, deflating employment by population or any other base in the correlated ratios causes the correlation coefficient measuring the degree of geographic association between two industries to vary with a redistribution of the base. This is true even when the redistribution does not affect the employment in the two industries in any way. For example, Table 3 lists employment in manufacturing and services for a sample of ten regions and the population for those regions. Also listed is a column showing the population in the ten regions arbitrarily redistributed among them. (One might consider this redistribution the result of opening and closing of large military bases.) For example, 20,000 employees were arbitrarily moved to Albuquerque while 20,000 were moved away from Akron. Below the sample data columns are the coefficients of correlation calculated using McCarty's R, Richter's measure, and Richter's measure using the arbitrarily-redistributed regional population figures to deflate industry employment in the ratios correlated. This arbitrary redistribution causes a change in the value of the coefficient of correlation. In this case the change is not large, but the example clearly shows that Richter's measure is not invariant under shifts in the base *not* affecting employ-

TABLE 3. Comparison of Measures of Association^c

SMSA	Employment in Manufacturing ^a	Employment in Services ^a	Population ^b	Redistributed Population
Akron	91.7	25.8	650	630
Albuquerque	8.2	21.9	288	308
Atlanta	108.8	67.0	1,216	1,246
Binghamton	44.3	10.1	297	267
Birmingham	64.8	27.4	644	684
Canton	58.3	14.0	356	316
Charlotte	34.0	17.3	360	410
Chicago	907.1	420.3	6,689	6,639
Denver	62.9	64.0	1,073	1,133
Detroit	579.1	175.9	3,987	3,927
Totals			15,560	15,560
Measure			r	t
McCarty's R			.971	11.39
Richter's R'			-.781	3.53
Richter's R' (after redistribution)			-.601	2.13

a. Source: U. S. Department of Labor, *Employment and Earnings Statistics for States and Area, 1939-1965*.

b. Source: U. S. Department of Commerce, *Estimates of the Population of Standard Metropolitan Statistical Areas, 1965*.

c. All figures in thousands.

ment in either industry. McCarty's measure is invariant under such re-distributions, and this is one of its advantages.

McCarty's R corrects for another possible defect which Richter recognized. When the ratios correlated are regional industry employment totals as a proportion of regional population, small outputs in small regions are weighted as heavily as large outputs in large regions. McCarty's R is not subject to this criticism.

Table 3's example highlights a possible dilemma in choosing between the two measures. Examination of the employment data for the two industries leads one to expect some degree of positive geographic association. Calculation of R gives a high value of .97, which may be high because of the high correlation in this particular sample between estimated employment for each industry and total regional employment for each industry. However, calculation of Richter's measure yields a negative value which seems intuitively to be misleading because there is no reason to expect that services will be repelled from a region as large as an SMSA by manufacturing, especially when the inclusion of business services in the service category is recognized.⁶ The negative coefficient may be reflecting instead the fact that when the proportion of a total constituted by one factor rises, there is a tendency for the proportions left for other factors to fall. In Table 3, the correlation between regional employment and regional population is higher than for most industries as indicated in Table 2, so that this possible negative aspect of McCarty's R is overemphasized in the example. Even recognizing this upward bias, one might prefer the measure that most closely accords with expectations. To partially correct for any possible bias from the correlation between employment and population in this paper, the value of McCarty's R is required to be significantly greater than .5 (at the 95 percent confidence level) before considering it to have identified a useful geographic association. Richter considered any value of his R' significantly greater than 0 to be useful. The appropriate value for the null hypothesis of no useful association is discussed further below.

The difference between McCarty's R and Richter's R' may also be regarded as a substitution of total national employment in an industry (used in R) for the population of the region (used in R') as the divisor in the ratios to be correlated. Thus, McCarty's ratio is X_{ij}/X_i while Richter's ratio is X_{ij}/P_j . Richter's measure emphasizes the relative importance of an industry to a region or the region's specialization in the industry, whereas McCarty's measure emphasizes the level at which an industry is present in a region relative to its average national presence. The latter would seem to be the more important emphasis for industrial location.

The ratios, X_{ij}/X_i , used in calculating McCarty's R have previously been utilized as the numerators of location quotients which measure the relative concentration of an industry in a particular region. A location

quotient is calculated as $(X_{ij}/X_{i.}) / (X_{.j}/X_{..})$. Because the denominators for location quotients for every industry in a region are identical, one could say that the ratios correlated by McCarty are actually location quotients, again emphasizing the contrast with Richter's measure which is more closely related to the degree to which a region specializes in or is dependent upon a particular industry.

As shown elsewhere [12: 50], McCarty's R is subject to neither the spurious correlation of Meyer and Kuh [10] nor the spatial autocorrelation of McCarty [14] and Cliff and Ord [3]. In previous studies where the industries utilized were more highly aggregated and/or only data from large metropolitan areas were used, it was more probable that each industry appeared in most regions at some nonzero level. Use of more disaggregated industries and a set of regions completely spanning the country makes it improbable that all, or even most, industries will be present in each region. In fact, among 199 4-digit SIC manufacturing industries used in one study, the number of regions in which each appears ranges from a low of 8 (in the case of SIC 3332, primary lead) to a high of 368 (in the case of SIC 2026, fluid milk) with a mean of 86 and a standard error of 120 [12: 163]. Some statistical consequences of utilizing data containing a large number of zero observations have been examined by Latham [11]. As recommended there, paired zero observations should be omitted from calculations of correlation coefficients measuring the strengths of geographic associations. Thus R^* in Table 1 is the measure of geographic association considered to be "best" among those reviewed.

The significance, if any, of negative coefficients of geographic association should be commented upon. The discussion above did not utilize a concept of agglomerative diseconomies. These could exist if, for example, firms in one industry are labor oriented and if regional wage levels rise whenever a second industry is present; then firms in the first industry might avoid locating near firms in the second. It seems likely, however, that negative coefficients result from pairs of industries having opposite positive orientations, such as market and material orientations. For this reason, it is suggested that negative correlations be treated as insignificant positive correlations.

Coefficients of correlation (R^*) between all different pairs (19701) of 199 manufacturing industries were calculated and the resulting distribution was examined with the use of frequency counts for coefficients falling in various magnitude intervals. As noted above, Richter considered any coefficient of correlation (R') significantly greater than zero as indicating geographic association between two industries. Several reasons for choosing a critical value for the coefficient of correlation greater than 0 to signify an association significant for policy purposes are detailed in the following discussion.

First, there is a tendency for industries to locate near each other even when they are not functionally associated. Because of concentration of

transportation facilities, power availability, intermediate goods, labor markets and other resources, the spatial patterns of industries in the United States are not random. Thus, even two industries not functionally connected in any way may frequently appear in the same region. Because many appear in a large number of regions (one appears in 368 of the 377 regions used in this paper) the frequency of joint location and, consequently, the measure of geographic association, is likely to be high. This would explain the high values of chi-squared found by Czamanski [4]. In fact, 8611, or 44 percent, of the coefficients computed in this study are significantly greater than 0 (at the 95 percent confidence level). It is not useful for policy purposes to say that 44 percent of all industry pairs have significant geographic association. The selection of any particular value must remain somewhat arbitrary. Theory only suggests that higher values indicate stronger association. The error committed in assuming that values significantly greater than 0 but less than .5 are not locationally significant is that some potentially useful associations will be overlooked. This error does not seem to be as harmful as erroneously identifying weak associations as potentially useful. The selection of a higher critical value guarantees that a larger proportion of those associations identified will be useful.

In this case, individual pairs of industries for which there is other evidence of geographic association were examined. On the basis of these examinations it was determined that values of the correlation coefficient should identify pairs of industries as being geographically associated when the coefficient is significantly greater than 0.5.⁸

Even using the much stronger criterion of being significantly greater than .5 for identifying useful geographic associations, 1040 such associations were found among the 199 manufacturing industries (this represents 5.28 percent of all possible associations). While the number of associations identified using the measure and criterion described may seem small, they should be of sufficient strength to be useful in industrial location policy decisions (provided, of course, that the industries are also identified as being linked in some causal fashion). The number of associations for any industry ranged from 0 (for 89 industries) to 64 (for SIC 3079, Miscellaneous Plastics Products) [12].⁹

Geographic Associations Among More than Two Industries

A logical extension of the preceding analysis of the geographic association between two industries is the analysis of geographic associations among three, four, or more industries. Spatial relationships involving more than two industries might be described with the aid of higher order correlation coefficients as suggested by Streit [17: 183]. Coefficients of multiple correlation might describe the degree of association between one industry and any group of others. Partial correlation coefficients might be used to describe the degree of association between groups of

industries with the effects of groups of other industries removed. While little work appears to have been done in these areas, means of using the pairwise associations described in this paper to identify more complex relationships have been developed [13]. In addition Bergsman *et al.* [2] applied factor analysis to regional industry employment distributions to identify sets of industries with similar locational patterns.

Conclusions

A number of measures of geographic association were evaluated. An adjusted coefficient of correlation computed between pairs of regional employment distributions was found to be the most appropriate measure of geographic association between pairs of industries. The results of calculating this measure for all pairs of 199 industries were reported and seem to be potentially useful for policy analysis. The use of partial and multiple coefficients of correlation to measure multilateral associations was suggested.

FOOTNOTES

¹The way in which measures of pairwise geographic association can be used to identify more complex locational relationships is described in Latham [13].

²The 363 sector input-output study breaks the manufacturing sector down into 4-digit Standard Industrial Classification (SIC) industries. More highly aggregated industries could have even more suppliers and markets or could have fewer depending upon the extent of aggregation and the particular industry. The numbers would have to be fewer at the 2-digit level because at that level of aggregation there are fewer than 30 sectors in all.

³An anonymous referee has made the obviously correct observation that if interindustry trade is transacted through wholesalers, input-output relationships provide no information about the spatial distribution of industry. This is precisely why it is important to identify the spatial distribution through some other means, such as those discussed in this paper. See Latham [13] for further elaboration on this point.

⁴This section draws upon pages 46-51 of Latham [12].

⁵If the explanation was the objective, then one would certainly be concerned that explanatory power was being attributed to a variable that was only correlated with a third explanatory variable, but even then care must be taken in removing the effect of a third variable. Suppose two highly correlated industries that are also highly correlated with population are identified. In such a case removing the effect

of population, as suggested in [2: 266], is clearly incorrect if the two industries are functionally related to each other but neither is functionally related to population. Causal geographic relationships can only be discovered with reference to functional factors such as are illustrated in [12] and [13].

⁶Richter found a large number of negative correlations in his study (over half of all such coefficients were negative) but did not comment on these [18: 26].

⁷Note that the correlation between X_{kj}/X_k and X_{lj}/X_l is identical to the correlation between X_{kj} and X_{lj} because X_k and X_l are constants for all observations. The discussion here is in terms of the ratios, however, to emphasize the difference between the measures of McCarty and Richter.

⁸The practice of choosing somewhat arbitrary values of a measure is not unique to locational analysis. For example, the concentration ratios and Herfindahl index values used in the study of industrial organization are somewhat arbitrary.

⁹Several "Miscellaneous" industries were included in this study. The inclusion of such industries in studies with highly aggregated industries, such as Rubber and Miscellaneous Plastics Products (SIC 30), might yield results of questionable utility for industrial location policy because of the diversity of products produced by firms in such a classification. In this study, however, the miscellaneous industries included each produce a significantly narrower range of products.

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