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EVIDENCE OF SPATIAL AUTOCORRELATION IN INTERNATIONAL PRICES

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Data from the International Comparison Programme (ICP) generate a number of analyses examining price and quantity relationships across countries. Although geographic location is sometimes evoked to explain differences across observations, it is seldom used to measure the extent of this interrelationship. Using ICP Phase V benchmark studies (Summers and Heston, 1991) at the level of household consumption for approximately 64 countries and 23 aggregate headings in 1985, this paper introduces such a measure, testing for spatial autocorrelation among price relatives with respect to three different measures of relative location: the pairwise existence of a common boundary, the distance between capital cities and the amount of trade between two countries.

INTRODUCTION

When real quantity and price data became available from the benchmark ICP studies, a number of subsequent analyses were generated examining price and income relationships across countries. Few of these studies however, explicitly model the spatial relationship between countries, although some have attempted to introduce geographical variables such as distance from the Equator (Theil and Finke, 1983), and temperature and rainfall (Barton and Summers, 1986), in the context of demand models for a sample of countries.

Spatial data differ from non-spatial data in that they are location specific and referenced with respect to each other. In some cases, this can be done visually, by coloring maps according to data intervals, for example, and verifying whether similar colors are clustered or scattered in a particular pattern. Statistical tests which determine the extent and degree of these spatial patterns are often more complex precisely because one fundamental tenet of most distributional assumptions is violated, that of independent observations. Spatial autocorrelation statistics such as Moran's I (1948), Geary's C (1954) and Getis' D (Getis and Ord, 1992, Ord and Getis, 1995) measure the degree of interdependence among observations, providing summary information about their arrangement.

One motivation for examining the existence of spatial autocorrelation with respect to prices is the possibility of testing the hypothesis that boundaries, distances or trade volumes capture differences in transport costs between the countries. For example, can we infer that great distances and/or small trade volumes reflect high transport costs and hence greater price differentials between two countries? The second motivation, and one that is explored in more detail here, is the consequence of spatially autocorrelated variables in the anlyses of a cross section of observations, such as those fostered by ICP data.

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The first section of the paper discusses spatial matrices and measures of autocorrelation, followed by a brief review of the price relatives in the benchmark study. The second section discusses the results of the correlation measures for a set of 23 aggregate headings, and highlights the degree of autocorrelation when different spatial matrices are used. In the third section, two simple regression models illustrate the persistence of autocorrelation among the residual estimates. The paper concludes in section four and suggests directions for future research areas in spatial trends.

1. Spatial Autocorrelation: Concepts and Measurements

Spatial Matrices

Space, or relative location, is often expressed in geographical applications as the distance between two points, or the length of the common boundary between two areas. The arrangement between all observations can then be expressed as a function of this distance, also known as a weighting function. One main difference between a lag function in time series analysis and a weighting function for spatial data is that time is unidirectional, whereas space is multidirectional, unless we are looking at, for example, the distribution of observations along a narrow strip of land, such as a highway.

Weighting functions are pairwise measures that express the relative locations between geographic regions, in this case, between countries. They are often represented as square matrices of $n \times n$ dimension, where n is the number of countries. An example is the average distance measured from the regions' centroids, or geographic centers. The value of the i-th row and j-th column in the matrix indicates the distance between the centers of regions i and j. Other measures of proximity include the proportion of the common boundary between two countries and their individual perimeter; a combination of distance and boundaries; or a nominal variable which indicates whether or not countries have boundaries in common. This latter measure is called a contiguity measure.

In this paper, three measures of relative location are used: the contiguity measure, the great circle distance between capital cities, and the volume of trade between countries, measured by their exports and imports. There are limitations to each of these measures, and they will be discussed in turn. The objective is to highlight the differences in the observed autocorrelation among prices patterns with respect to the different definitions of relative location, illustrating how their influence varies among consumption headings.

(i) Contiguity

A simple contiguity matrix $[\mathbf{W}]_{64\times 64}$ of the 64 countries is created. Each element w_{jk} equals one if country j and country k share a boundary, and zero otherwise. If we take four countries in Europe as an example, Germany, Belgium, the Netherlands and the U.K., the corresponding weight matrix $[\mathbf{W}]_{4\times 4}$ is given below.

The w_{jk}s for $j =$ *United Kingdom* are all 0, since it is isolated from the other countries in this sample. The same would be true of Japan and as will be shown

TABLE 1

CONTIGUITY WEIGHT MATRIX

Contiguity $\mathbf{W}_{ij}$	Germany	Belgium	Netherlands	U.K.
Germany	0	1	1	0
Belgium	1	0	1	0
Netherlands	1	1	0	0
U.K.	0	0	0	0

in the next section, the net effect of the zero designation in these countries is to exclude them from the autocorrelation statistic. The result is a statistic which measures autocorrelation among countries in contiguous regions. The notion of contiguity is somewhat similar to the use of regional dummy variables in estimating equations, although the **W** matrix provides additional pairwise information.

(ii) Distance

The second measure of spatial proximity is a distance matrix, measured in kilometers and defined as the shortest great circle distance between each country's capital city.[1] That is, w_{jk} equals zero if $j=k$, but is a number greater than zero for all other entries. The advantage of using distances rather than contiguity is that islands and other countries which may be physically isolated will have a non-zero weight, and will thus be included in the correlation coefficient. It also provides more information than a regional dummy variable since it distinguishes, distance-wise, what may be viewed as peripheral countries from core countries. Table 2 shows the distance matrix for the same countries in the contiguity matrix.

Note that in the contiguity matrix, the larger the value of the element w_{ij} (1 versus 0), the closer country i is to country j. That is, one indicates countries

TABLE 2

DISTANCE MATRIX

Distance kilometers and ($\mathbf{W}_{ij}$)	Germany	Belgium	Netherlands	U.K.	Total
Germany	0	659	593	925	2177
	(0)	(0.35)	(0.39)	(0.25)	(1)
Belgium	659	0	192	315	1166
	(0.16)	(0)	(0.53)	(0.32)	(1)
Netherlands	593	192	0	335	1120
	(0.17)	(0.53)	(0)	(0.30)	(1)
U.K.	925	315	335	0	1575
	(0.15)	(0.44)	(0.41)	(0)	(1)

[1]The distance between cities is calculated by the great circle formula. If (lat_1, $long_1$) and (lat_2, $long_2$) are the coordinates of a pair of cities, the distance in kilometers between them is given by:

$$Distance = Rad * ACOS\,[SIN\,(lat_1) * SIN\,(lat_2) + COS\,(lat_1) * COS\,(lat_2) * COS\,(long_1 - long_2)$$

where Rad = 111.32 kilometers and the trigonometric function arguments are in degrees.

TABLE 3

TRADE MATRIX

Trade 1985 current US$ 000's and (W_{ij})	Germany	Belgium	Netherlands	U.K.	Total Exports
Germany	0	12,561,492	15,787,700	15,672,378	44,021,570
	(0)	(0.26)	(0.42)	(0.32)	(1)
Belgium	9,952,321	0	7,633,262	5,153,740	22,739,323
	(0.46)	(0)	(0.35)	(0.19)	(1)
Netherlands	20,480,874	9,595,346	0	6,480,544	36,556,864
	(0.52)	(0.25)	(0)	(0.23)	(1)
U.K.	11,577,807	4,296,618	9,492,132	0	25,66, 556
	(0.52)	(0.18)	20.30)	(0)	(1)
Total imports	42,911,002	26,453,456	32,913,094	27,306,662	128,684,214

Source: "Direction of Trade Statistics", *International Monetary Fund, 1992.*

which are neighbors while zero indicates there is no common boundary between the two. In the distance matrix, the larger the value, the greater the distance, and hence it is the inverse of the distance which should be used as elements of the matrix. In addition, the elements are normalized so that row totals equal one. This means that the relative distance is assumed to be more important as a measure of relative location than absolute distances. For example, the distance between Germany and the U.K. is expressed as a proportion of the total distance between Germany and all other countries in the sample. The normalization mitigates the effect of having much greater distances for large countries, and to some extent, the distortions from using only one city in each country as a reference point. The relative distance, or normalized measure, is given in parentheses. Unlike the contiguity matrix, it is not symmetric.

(*iii*) *Trade*

The third proximity matrix reflects the trade flows between countries and is based on w_{ij}, the volume of exports from i to j. Unlike the original distance matrix, exports w_{ij} are usually different from imports w_{ji}, and $\mathbf{W}$ is not symmetric. Table 3 shows the calculation of the w_{ji}.

In the trade matrix the higher value indicates more exports, and hence more interaction between countries, so that the direction of proximity is similar to that of the contiguity matrix. Thus, there is no need to invert the values as was done is the distance matrix. Since we are interested in trade volumes, rather than exports, row and columns are added, and the trade between two countries is expressed as a proportion of total exports and imports. These values are given in parentheses.

The volume of exports from Germany to the Netherlands and the U.K. was similar (US$ 15 billion), but the imports from the Netherlands to Germany exceed those from the U.K. so that the resulting entry in the trade matrix for Germany–Netherlands is higher (0.42) than for the U.K. (0.32).

Autocorrelation Coefficients

An autocorrelation coefficient is a general statistic which attempts to capture the systematic variation of the values of a variable. When the variation is related to physical location, the coefficient is usually evaluated with respect to distance, contiguity, boundaries, and other geographic weighting functions such as the spatial matrices discussed in the previous section. They differ from traditional correlation coefficients in that they measure the interrelationship (defined by the weighting function) between observations on one variable, rather than the relationship between the i-th value of one variable and the i-th value of a second variable. The null hypothesis for testing the presence of spatial autocorrelation is that there is no relation between the values of the data and their relative weights, that is, they appear to be randomly and independently assigned. The autocorrelation statistic that is used here is Moran's I-statistic, a variation of the general cross-product statistic (Upton and Fingleton, 1985). It is the weighted ratio of the covariance of the variable divided by its variance:

$$(1)\qquad \text{Moran's } I = \frac{n \sum_{j=1}^{n} \sum_{k=1}^{n} w_{jk}(x_j - \bar{x})(x_k - \bar{x})}{S_0 \sum_{j=1}^{n} (x_j - \bar{x})^2}$$

where, for each heading i, $x_j = pr_{ij}$, $x_k = pr_{ik}$, $n = 64$ and pr_{ij}, is the price relative for the i-th item in the j-th country:

$$(2)\qquad \bar{x} = \frac{1}{n} \sum_{j=1}^{n} pr_{ij}$$

$$S_0 = \sum_{j=1}^{n} \sum_{k=1}^{n} w_{jk} (j \neq k).$$

The price relatives are defined in equation (4).

With no autocorrelation present, Moran's I approaches $-1/(n-1)$. With maximum positive autocorrelation, I approaches one. Positive spatial autocorrelation is measured as the clustering or juxtaposition of similar values; negative autocorrelation describes the tendency for dissimilar values to cluster. The lack of autocorrelation suggests that the actual arrangement of values is one that we would expect from a random distribution. In the case of distance weights, positive autocorrelation implies that countries which are closer have similar prices relatives, while in the case of the trade matrix, positive autocorrelation denotes similar prices in countries with greater trade interaction. Note that unlike classical correlation coefficients, the Moran values are not restricted to the -1 to 1 range.[2]

Relative Prices

The price relatives for household expenditures in 64 countries were calculated at the aggregate level for 23 headings, ranging from food to expenditures on

[2]The formula for the variance of Moran's I is given below. Cliff and Ord (1971) show that it is possible to assume a normal distribution under the null hypothesis in "fairly liberal conditions." Upton and Fingleton (1985) suggest that 20 locations (countries in this paper), are generally sufficient to assume normality.

restaurants and hotels. The price relative of each heading i in country j is the weighted ratio of the sum of the nominal item prices to real prices, where the weights are the item quantities: equation (3). Each heading i consists of a number of items k. For example, food is made up of 35 food items, ranging from rice to ice cream. These price relatives are divided by the overall purchasing power of the currency: equation (4), normalizing the units across countries.

$$PPP_j^i = \frac{\sum_{k \in i} p_{kj} q_{kj}}{\sum_{k \in i} \pi_k q_{kj}}. \tag{3}$$

π_k is the international price of each item k in heading i. For example, the price relative for food in Japan ($PPP_{\text{Japan}}^{Food}$) is expressed as the sum of the expenditures in yen of the 35 food items divided by its expenditures expressed in international currency units (ICUs). This yen/ICU ratio is then divided by Japan's overall purchasing power parity for all consumption goods (obtained in exactly the same manner as in equation (3), but summing over all goods, rather than over each heading), to produce a normalized price relative which is comparable across all countries:[3]

$$pr_{ij} = \frac{PPP_j^i}{PPP_j} \tag{4}$$

The pr_{ij}s are unit free and are the values used in Moran's I-statistic given in Equation (2). Table 4 shows the mean and the coefficient of variation of the price relatives.

Footnote 2 continued: The distribution of Moran's I under randomization (Upton and Fingleton, 1985, p. 171):

$$E(I) = -\frac{1}{(n-1)}$$

$$Var(I) = \frac{n[(n^2-3n+3)S_1 - nS_2 + 3S_0^2] - k[n(n-1)S_1 - 2nS_2 + 6S^{2_0}]}{(n-1)(n-1)(n-3)S_0^2} - \frac{1}{(n-1)^2}$$

where

$$k = \frac{m_4}{m_2^2} \qquad m_r = \frac{1}{n}\sum_j (x_j - \bar{x})^r \qquad S_0 = \sum_j \sum_k w_{jk} \; (j \neq k)$$

$$S_1 = \frac{1}{2}\sum_j \sum_k (w_{jk} + w_{kj})^2 \; (j \neq k) \qquad S_2 = \sum_j (w_{j0} + w_{0k})^2;$$

$$w_{j0} = \sum_k w_{jk}; \qquad w_{0k} = \sum_j w_{jk}.$$

[3]If we were to take individual items rather than their aggregate heading, equation (3) would reduce to

$$PPP_{ij} = \frac{p_{ij} q_{ij}}{\pi_i q_{ij}} = \frac{p_{ij}}{\pi_i}$$

and equation (4) would be expressed as

$$pr_{ij} = \frac{p_{ij}}{PPP_j} \times \frac{1}{\pi_i}.$$

TABLE 4

PRICE RELATIVES

Price Relatives	Mean	CV(%)
1. Food	1.023	16.0
2. Beverages	1.231	62.2
3. Tobacco	1.094	37.9
4. Clothing	0.973	29.3
5. Footwear	1.112	28.4
6. Gross rents	1.376	55.0
7. Fuel and power	1.251	38.6
8. Furniture	1.223	28.2
9. Household textiles	1.438	39.5
10. Appliances	1.340	44.1
11. Other household goods and services	1.057	34.3
12. Pharmaceutical & therapeutical goods	1.192	36.1
13. Health services	0.756	66.3
14. Transport equipment	2.331	60.3
15. Transport operating costs	1.040	68.6
16. Purchased transport services	1.400	48.0
17. Communication	1.456	50.4
18. Recreation equipment	1.574	53.8
19. Recreation services	0.800	64.8
20. Books, periodicals	1.841	41.4
21. Education	1.317	42.3
22. Personal and financial services	1.074	26.9
23. Restaurants and hotels	0.920	39.4

In general, a lower mean implies that for most countries, the heading is relatively less expensive than other goods and services. Recreation services, for example, has a mean of 0.800, and is relatively cheaper, on average, than household appliances, furniture and transport equipment. The relatively lower cost of services is what one would expect in developing countries. Since the majority of countries in this sample are developing countries, it is precisely this effect which is captured by the recreation services price relative.

Within the recreation services heading, the higher price relatives are found in Spain (2.045), with Luxembourg, Italy, Belgium and France following close behind. Another heading with a low mean price relative is health services at 0.756. Here, both the U.S. and Australia have fairly high price relatives for health services: 1.775 and 1.648, respectively.

If we look at a relatively expensive heading, such as transport equipment (mean of 2.331), Japan is lowest, with 0.645, followed by Barbados, Canada and Sweden, while Iran, Bangladesh, Malawi, Mauritius and Benin have the higher price relatives. On the other hand, the food category with a mean of 1.023 has low price relatives for Australia (0.680), New Zealand, Germany and the U.K., while the high price relatives are found in Bangladesh (1.610), Mauritius, Saint Lucia, Nigeria and Nepal.

One approach to disentangling the price-income relationship is through consumer demand functions estimated across countries; a discussion of this approach can be found in Kravis, Heston and Summers (pp 347–374, 1982). Income levels are introduced as an additional explanatory variable in section 3, but first, we look at the autocorrelation within the price relatives *per se*.

TABLE 5

SPATIAL AUTOCORRELATION: MORAN'S I-STATISTIC

Aggregate Heading	Cont.	Distance	Trade
1. Food	0.326*	0.126*	0.113
2. Beverages	0.466*	0.164*	0.031
3. Tobacco	0.230*	0.159	0.087
4. Clothing	0.114	0.080*	0.193*
5. Footwear	0.021	0.079*	0.135*
6. Gross rents	0.618*	0.197*	0.081
7. Fuel and power	0.363*	0.082*	−0.042
8. Furniture	0.046	0.039*	0.028
9. Household textiles	0.644*	0.155*	0.118*
10. Appliances	0.709*	0.186	0.073
11. Other household goods & services	0.005	0.023	0.149*
12. Pharmaceutical & therapeutical goods	0.426*	0.0366	0.102
13. Health services	0.472*	0.255*	0.118
14. Transport equipment	0.483*	0.145*	0.144*
15. Transport operating costs	0.478*	0.148*	0.011
16. Purchased transport services	0.355*	0.094*	0.005
17. Communication	0.485*	0.205*	0.205*
18. Recreation equipment	0.501*	0.150*	0.117
19. Recreation services	1.211*	0.326*	0.106
20. Books, periodicals	−0.040	0.105*	0.054
21. Education	0.245*	0.867*	0.085
22. Personal & financial services	0.397*	0.140*	0.170*
23. Restaurants and Hotels	0.350*	0.180*	0.078
Consumption	0.122*	0.132*	0.028
Total significant	19	20	7
% Significant	82.61%	86.96%	30.43%

Note: * indicate headings whose distribution is *not* random at the 0.05 significance level for the Moran statistic.

2. SPATIAL AUTOCORRELATION: PRELIMINARY EVIDENCE

The Moran statistics for the 23 aggregate heading levels are shown in Table 5. Asterisks indicate headings whose distribution is *not* random at the 0.05 significance level for the Moran statistic.[4]

Note that all headings are significantly autocorrelated by at least one weight matrix. In addition they are positive, suggesting a tendency for similar price relatives to cluster. Also, overall consumption price relatives, which measures the price level of consumption relative to GDP price level, has a significant Moran value for both contiguity and distance matrices. This suggests that countries which are contiguous or relatively close are likely to have similar consumption price levels.

Figures 1 and 2 highlight the differences in the degree of autocorrelation using the three matrices. The ratios of Contiguity to Distance Morans in Figure 1 oscillate above zero with Pharmaceuticals standing out as having a large autocorrelation statistic for Contiguity relative to Distance. The Distance and Trade ratios are generally smaller smaller than those in Figure 1, but there are three pronounced peaks (Transport Equipment and Transport Operating Costs and

[4]Recall that the Moran is not restricted to the $-1+1$ range, and that a value of 0 does not necessarily imply zero correlation. The expected Moran under the null hypothesis of randomness is $-1/(n-1)$, which equals -0.01587 when $n=64$.

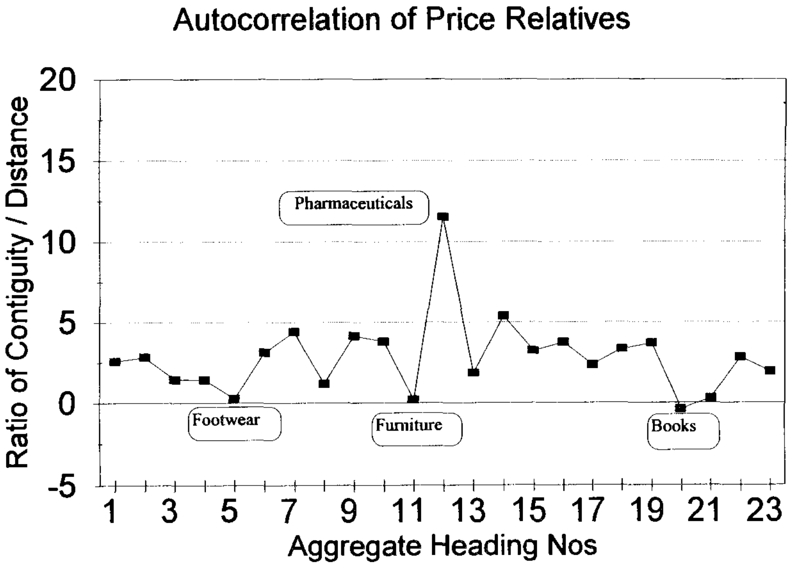

Figure 1. Contiguity/Distance

Education) and one pronounced valley (Fuel and Power). The high peaks indicate a large Moran value for Distance but a low one for Trade, suggesting that closer countries have similar prices, even though they may have very little interaction. The valley (a negative ratio) is a result of a positive coefficient for Fuel and Power using the Distance matrix and a slightly negative, but not significant one for the Trade matrix. Thus the interpretation is similar to that of the peaks, with prices appearing to be more similar when countries are closer, but not necessarily when they trade proportionately more.

Recreation services (Moran = 1.211) have the most statistically significant degree of positive spatial correlation among all headings. Only a few headings: Clothing (0.114), Footwear (0.021), Furniture (0.046), Other Household Goods and Services (0.005), and Books and Periodicals (−0.040), appear to be randomly distributed, and are not statistically significant with the Contiguity matrix. However, for Clothing and Footwear, the Moran values using the Distance matrix are higher, suggesting that distance rather than boundaries are more likely to capture price patterns for these categories.

This is also true when we use the Trade matrix as the measure of spatial proximity. That is, the Moran values increase in magnitude as well as in statistical significance, suggesting that although countries may be physically distant, if they engage heavily in trade their relative prices of Clothing and Footwear are likely to be similar. This would be consistent with a trade equilibrium view of national markets. Conversely, when there is less trade, prices are less similar. In this case, we may speculate that the market has not reached its equilibrium among those countries, or that transport costs are higher than the price differential for those item headings.

Other categories appear to become less correlated with distance or trade. Many of these are for services and include nontradable goods, for example, Gross

Rents, Health Services, Education and Recreation Services. The tendency is for relatively expensive or cheap services and nontradable goods to be similar priced in nearby countries, regardless of trade flows. The similarity may reflect physical resources in the case of agricultural products, for example, or environmental characteristics, such as in Transport Operating Costs, or the cost of labor. Price similarities for these headings appear to be independent of the interaction between the countries as measured by their trade flows. Note that the Transport Operating Costs reported here for each country are internal operating costs, and do not reflect transport costs between countries. Headings which include tradables but are not significantly correlated with trade are Tobacco, Fuel and Power, Pharmaceutical Goods and Books and Periodicals. One explanation may lie in the tendency for prices of items in these categories to be regulated by national governments. See Aten (1995) and Heston, Summers, Aten and Nuxoll (1995) for other kinds of comparisons of tradable and nontradable goods and services.

Finally, there are four exceptions to the above tendencies: Household Textiles, Transport Equipment, Communication Equipment and Personal and Financial Services. These remain significantly positively spatially autocorrelated with all measures of proximity. The result implies that the relative prices for the goods and services in these headings are similar among physically close countries *and* among countries with apparently close trade relationships.[5]

3. Demand Analysis and Spatial Autocorrelation—An Example

Do the price patterns correspond to differences in income levels as well as to differences in distance or trade relations? The motivation for this question is twofold. The first is to uncover a reason for interdependence among the values observed in the price relatives, and the second is to illustrate how this interdependence may affect model results of frequently used regressions involving ICP price relatives. We begin by estimating the relation between prices and incomes and between demand quantities and prices, holding incomes constants. Incomes are measured by countries' per capita national product level (GDP) and demand by per capita quantities valued at purchasing power parities.

If the regression residuals are spatially autocorrelated or correlated with trade flows, then the models may be misspecified. An additional variable, related to location or trade, should be included in the model. If the missing relevant variable is not included, then the ordinary least squares (OLS) estimation will result in

[5]The Moran statistic at the more detailed level shows some interesting patterns with respect to the 23 heading level of Table 5. The number of headings which have significant Moran values as a percentage of the total number of headings is very consistent: approximately 80 percent for contiguity and distance and 30 percent for trade. There is an increase from 17 percent to 25 percent of headings which are significantly correlated using all three matrices. More strikingly, perhaps, is the increase from none to 13 percent (15/111) of headings which are randomly distributed in all three cases of proximity. These headings include, in the food category: Other cereals, Other meats, Processed fish and seafood, Other milk products and Coffees; Electricity, Repairs to furniture and floors, and Long distance air transport in other categories. Perhaps one reason why they may be more random here than at the aggregate level is because of the nature of the basic heading price comparison. Often countries' selection of items which best match ICP specifications vary greatly, affecting sample size and variance.

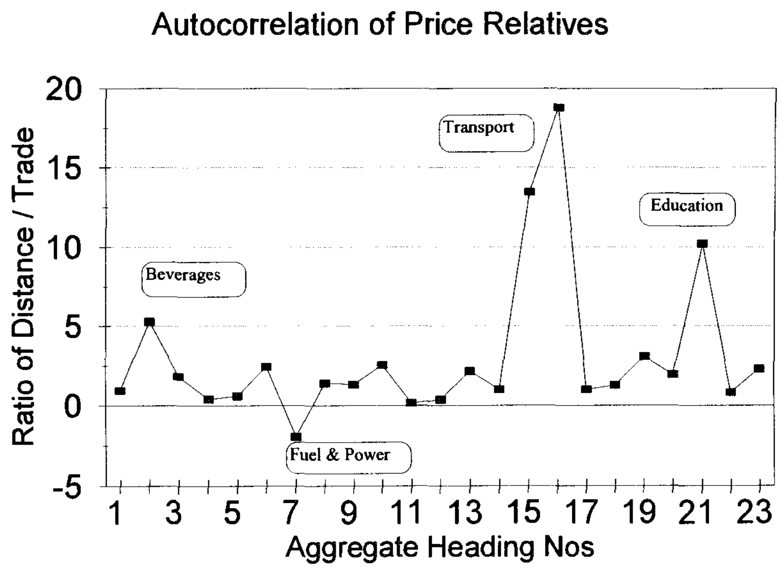

Figure 2. Distance/Trade

inefficient estimates. The regression coefficients for the two equations are discussed briefly, followed by a look at the distribution of their residuals.

Regression Results

The first equation is that of the price relative variable regressed on income levels (PY) and the second equation is demand quantities regressed on prices and incomes (QPY). Both are in log form, and are given below:

$$\ln P = \alpha_0 + \alpha_1 \ln Y + \varepsilon \tag{5}$$

$$\ln Q = \beta_0 + \beta_1 \ln Y + \beta_2 \ln P + \mu \tag{6}$$

Q is the real per capita quantity consumed in each country, valued at international prices. Y is total GDP, also in real terms, and P is the heading price relative. Each equation has 64 observations, corresponding to the sample countries, and there is one equation per heading, a total of 23 equations.[6]

In the first regression, equation (5) or PY, the income parameter α_1 is positive and significant (at a 95 percent confidence level) for 9 headings and negative and significant for 8 headings. Thus out of 23 estimated coefficients, a total of 17, or nearly three quarters, are significant. Interestingly, the headings which have positive income coefficients and are also significantly positively autocorrelated with respect to prices consist predominantly of service categories: Gross Rents, Health Services, Transport Operating Costs, Recreation Services, Education, Personal

[6]The full set of regressions for approximately 110 detailed item headings were also estimated, but for the purposes of this paper, only the aggregate results are discussed. The actual coefficients (income in the case of equations (5) and price and income in equations (6)) and their standard errors are *not* presented here due to space limitations, but are available from the author.

and Financial Services and Restaurants and Hotels. On the other hand, prices of Food, Fuel, Furniture, Household Appliances, Transport Equipment and Recreation Equipment are relatively higher in poorer countries, and these price relatives are also positively spatially autocorrelated. This suggests that income levels explains the autocorrelation of the prices, since wealthier countries, with higher relative prices for service headings may be relatively clustered (as in Europe) and poorer nations would also be relatively close in the sample (as in Africa). However, if autocorrelation persists in the residual estimates, the significance of the models may be overstated, and variables other than income are needed to explain price differences.

In the demand regression, equation (6) or QPY, all of the estimated income coefficients are significant and positive, and all but two price coefficients are significant and negative. The two that are not significant, Tobacco and Education, have negative price coefficients, but are also likely to be price-regulated. Thus it would appear that the regression models are capturing, to a significant degree, the price-quantity-income relationship across countries. If this is true, the apparent spatial pattern of relative prices is explained to a large extent by income differences, and the correlation of prices with location may be spurious. However, the significant model estimates may be misleading. If the residuals of the above estimating equations are autocorrelated, the above model results need to be correct. Ordinary least squares (OLS) estimates assumes that the errors are not correlated with one another. If this assumption is wrong and the errors are positively autocorrelated, the model R^2s are upwardly biased, and the variance of the parameters are underestimated. Thus, although the regression coefficients remain unbiased in repeated samples, the model results may not be as reliable as one would surmise from the initial results. The section below tests for residual autocorrelation in each of the estimating equations above.

Autocorrelation of the Residuals

The Moran statistic was estimated for the residuals in each heading. The moments under randomization however, are biased (Cliff and Ord, 1973, p. 92), unless there are "a lot of observations for a simple model" (Upton and Fingleton, 1985, p. 337). This is because the Moran for the price relatives are based on the independent observed values, but the residuals are subject to the linear constraints from the estimation of the parameters in the demand function.

Fifteen out of the 23 headings for the PY regressions have significantly spatially autocorrelated residuals, as do 11 of the QPY regressions. They are listed below. The signs indicate positive and negative autocorrelations.

The autocorrelated residuals imply that the price variance which cannot be "explained" by differences in income levels across countries is related to either spatial proximity or to trade interaction. A significantly positive spatially autocorrelated residual implies a more clustered distribution than what would be expected if the residuals were independently and randomly assigned. For example, in equation (5) PY, Transport Equipment and Recreation Equipment residuals are negative using the contiguity matrix. They both had negative income coefficients and positive price relative autocorrelation (Table 5) using contiguity and distance

TABLE 6

SIGNIFICANTLY AUTOCORRELATED RESIDUALS: EQUATION (5)

Residuals PY

Contiguity	Distance	Trade
Tobacco (−)	Clothing (+)	Beverages (−)
Transport equipment (−)	Footwear (+)	Fuel & power (+)
Recreation equipment (−)	Pharmaceutical & therapeutical products (+)	Furniture (+)
Books and periodicals (−)	Transport operating costs (+)	Appliances (−)
	Restaurants and Hotels (+)	Pharmaceutical & therapeutical products (−)
		Transport equipment (+)
		Purchased transport services (−)
		Restaurants and Hotels (−)

definitions. Thus, one would expect higher prices for the two headings in lower income countries, and we would expect the higher prices to be clustered geographically, but the remaining variance among price relatives are dispersed in an apparently non-random pattern: large residuals are close to small residuals in an alternating pattern. The more service-oriented headings of Transport Operating Costs and Restaurants & Hotels have positively autocorrelated residuals for distance (Table 6), positive income coefficients in the PY regressions and positive price relative autocorrelation (Table 5). This suggests that high price relatives and higher incomes are clustered (as are lower incomes and lower price relatives for these headings) and that the remaining variance not attributed to incomes is also clustered. It may be that higher residuals are associated with lower income countries, which would also suggest heteroskedasticity in the error term.

A similar interpretation holds for the residuals of the equation (6) QPY, although now the residuals are the unexplained variance of the per capita quantities, rather than the price relatives. For example, Restaurants & Hotels have positively autocorrelated residuals using both the contiguity and the distance matrix (Table 7), and positive income coefficients and negative price coefficients in QPY. If the residual autocorrelation in PY was due to differences in quantities consumed across countries, we would not expect the errors in QPY to remain

TABLE 7

SIGNIFICANTLY AUTOCORRELATED RESIDUALS: EQUATION (6)

Residuals QPY

Contiguity	Distance	Trade
Fuel & power (−)	Footwear (−)	
Household textiles (+)	Transport operating costs (−)	
Appliances (+)	Communication (+)	
Pharmaceutical & therapeutical products (+)	Books & periodicals (+)	
Purchased transport services (−)	Restaurants & Hotels (+)	
Recreation services (−)		
Restaurants & Hotels (+)		

autocorrelated. This indicates the persistance of a locational pattern in the distribution of relative prices and incomes. It is only when the trade matrix is used that the autocorrelation is no longer significant, suggesting that such a variable should be included in regressions of this nature.

There are a number of significantly autocorrelated residuals using the trade matrix for the first equation but none using the second. One explanation is that the demand relationships already reflect the trade interaction between countries, so that residuals are more likely to be correlated with factors other than trade, such as a location specific factor. The overall number of significantly autocorrelated headings for residuals is less than the number for price relatives. The spatial pattern of the price relatives can therefore be explained to a large extent by differences in demand and income levels across countries. The interpretation is that differences in price relatives can be explained by both differences in income levels *and* geographic location, but not singly by income levels or geographic location or trade interaction

4. Conclusion

The ICP methodology, which has used the purchasing power parity of different currencies to calculate the real price and income variation in approximately 90 benchmark countries since 1970, is a relatively new body of information that has yet to be explored by spatial statisticians and economic geographers.[7] This paper introduces the spatial referent in a benchmark study of household consumption prices for 1985, and analyses the distribution of the price relatives for 23 aggregate headings in 64 countries.

The first section of the paper explains the concept of spatial weight matrices and calculates the spatial autocorrelation of the actual price relatives as measured by the Moran statistic. This was done for each of the headings. Three measures of spatial proximity were used: contiguity, distance and trade. In the case of headings composed of mostly tradable goods, there was positive spatial autocorrelation and positive "trade" autocorrelation. That is, countries which were distant from each other were more likely to have similar prices if their trade interaction was greater, a very plausible result. For headings which included nontradable goods and services, the relative prices were independent of their trade flows. Headings which include tradables and have large barriers to trade, such as tobacco and alcoholic beverages, have relative prices independent of trade flows.

The final section highlighted the importance of autocorrelation using two estimated price-income relationships: prices regressed on incomes, and quantities regressed on prices and incomes. The variables were the per capita quantity demanded for each category, the per capita income, as measured by the real Gross Domestic Product in each country, and the relative prices of the service or commodity. The majority of the model coefficients were of the expected signs and statistically significant, suggesting that much of the price differential among

[7]The ICP has calculated benchmark comparisons of purchasing power parities and real product for detailed and aggregate levels of expenditure over 5 year intervals over the period 1970–90. The countries used in this paper are the 1985 benchmark countries only.

countries is due to differences in income and demand levels. However, these estimated coefficients assume a spherical distribution of the residuals, that is, the residuals should have equal variance and zero covariance. If this assumption does not hold, the coefficient of determination is overestimated and a different estimation procedure or a different model should be used.

This assumption is tested by looking at the distribution of the residuals. In many cases, there appear to be non-zero covariance, that is, there was evidence of spatially autocorrelated residuals. This suggests that although income and demand quanities appear to explain much of the price differentials among countries, the model variances may be underestimated due to the presence of autocorrelation, and a location or spatial factor should be incorporated in the estimating equation.

Another consequence of the existence of spatially autocorrelated price relatives or residuals is that care must be taken when producing model estimates for a cross-section of countries, either at the aggregate or at the detailed heading level. For example, the sample used here consists of the ICP benchmark countries, and are thus inputs to models estimating aggregate consumption (as well as investment and government, which have been excluded in this paper), for non-benchmark countries. One assumption that is often made is that there are regional price and income differences, that is, systematic patterns with respect to countries in Europe and Africa, for example, and the previously centrally planned economies of Eastern Europe. Thus, a dummy variable for a continent or for a group of countries is used to account for these patterns. By going further into the spatial aspect of the patterns, we can uncover the reason *why* a regional factor may be important, and hence calibrate our models more accurately as we incorporate this additional information.

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