CITY SIZE DISTRIBUTIONS AND SPATIAL ECONOMIC CHANGE

Eric Sheppard

March 1982
WP-82-31

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

FOREWORD

Declining rates of national population growth, continuing differential levels of regional economic activity, and shifts in the migration patterns of people and jobs are characteristic empirical aspects of many developed countries. In some regions they have combined to bring about relative (and in some cases absolute) population decline of highly urbanized areas; in others they have brought about rapid metropolitan growth.

The objective of the Urban Change Task in IIASA's Human Settlements and Services Area was to bring together and synthesize available empirical and theoretical information on the principal determinants and consequences of such urban growth and decline. The Task was concluded in 1981, and since then attention has turned to disseminating its principal results such as those presented in this paper.

Classifying cities in some orderly way to define and compare urban systems has been a challenge to scholars for many years. Cities have been compared according to their size, but this approach often removes them from the social and economic system of which they are an integral part. This paper gives a brief exposition of the city size distribution concept and explains why such an analysis frequently does not adequately describe the results of urban development processes.

A list of recent publications in the Urban Change Series appears at the end of this paper.

Andrei Rogers
Chairman
Human Settlements
and Services Area

ACKNOWLEDGMENTS

Thanks are due to Helga Leitner for advice and technical help with the empirical tests.

ABSTRACT

The concept of the city size distribution is criticized for its lack of consideration of the effects of interurban interdependencies on the growth of cities. Theoretical justifications for the rank-size relationship have the same shortcomings, and an empirical study reveals that there is little correlation between deviations from rank-size distributions and national economic and social characteristics. When interdependencies are considered, there is little reason for city sizes to evolve into a rank-size or any other relationship. Thus arguments suggesting a close correspondence between city size distributions and the level of development of a country, irrespective of intranational variations in city location and socioeconomic characteristics, seem to have little foundation.

CONTENTS

1. INTRODUCTION 1

2. EXPLANATION OF THE RANK-SIZE RELATIONSHIP 4

3. EMPIRICAL COMPARISONS 10

Past Empirical Tests of Primacy 10
A New Test 17
City Sizes and Development 23

4. CITY SIZE AND SPATIAL INTERACTION 26

Gibrat's Law 30
City Size and Migration Models 33
Interactions and Urban Growth 35
Why the Rank-Size Rule? 37

5. CONCLUSIONS 42

APPENDIX: EMPIRICAL STUDY OF DEVIATIONS FROM THE RANK-SIZE RELATIONSHIP 45

REFERENCES 54

LIST OF PAPERS IN URBAN CHANGE SERIES 58

CITY SIZE DISTRIBUTIONS AND SPATIAL ECONOMIC CHANGE

1. INTRODUCTION

One concept that has enjoyed recurrent popularity as a way of representing aspects of an urban system is the study of city size distributions. According to this theory, the ranking or comparing of cities is accomplished by first isolating an urban system and then selecting the cities out of that system and arranging them on a graph, ranking them from largest (rank one) to smallest in population size on the abscissa and plotting their actual population size on the ordinate axis. The result is obviously a downward sloping graph depicting the relative sizes of the different cities. It will be noted at the outset that by constructing this distribution the cities are removed entirely from their context. No information is retained about the relative location of the cities in space, their economic function, or any other aspects that might explain how they interact together within the system. Thus it must immediately be questioned whether anything is retained in this graph that is of use in predicting how an urban system develops.

However, city size distribution graphs have remained a popular tool for certain researchers for possibly two reasons. First, they are easily constructed for any urban system, assuming that the boundaries to the system and the concept of a city can be reasonably defined. Few other features of an urban system can be so elegantly depicted. Second, early empirical work by Zipf (1949) suggested that a large number of observed city size distributions could be approximated by the so-called rank-size relationship (first suggested by Pareto, cf. McGreevey, 1971). This relationship is particularly simple, since if the two axes of the city size distribution are scaled logarithmically the distribution becomes a negative sloping straight line. Zipf argued that a particular case of this, when the slope equals 1, represents a desirable situation where forces of concentration balance those of decentralization. He characterized this as the rank-size rule.

Thus Zipf presented urban research with an empirical regularity of a particularly elegant form—a form that in a sense was crying out to be explained. Simultaneously, he suggested that it represents a desirable norm for urban systems to achieve. This latter notion was reinforced by research showing that the United States urban system, representing a nation that many regarded as the most developed in the world, almost spectacularly fit the rank-size rule over a number of decades (Madden 1956). Such a belief in the rank-size relationship as a desirable feature has remained as an undercurrent in the settlement system literature ever since.

It is not at all clear, however, how such a severe abstraction of the urban system can be related in any systematic way of the development of its cities. The range of city sizes results from the growth of individual cities, and growth in turn depends on the relative position of cities within the urban system. Since information on this is not retained within the city size distribution concept, it would seem difficult to construct any link between a system's growth and its city size distribution without invoking some kinds of macro-laws of urbanization that transcend or nullify the importance of the fates of individual cities. Such a challenge has not daunted urban researchers, and indeed a number of theoretical and empirical studies have appeared attempting to do just this. The purpose of this paper is to evaluate and update these studies. The conclusions are both negative and positive. They are negative in the sense that the theoretical justifications reviewed are found to be weak and that an empirical study reveals no evidence that deviations from the rank-size rule can be explained by socioeconomic indicators. These conclusions are positive in the sense that they support intuition; city size distributions are so far removed from the reality of urban interdependencies and growth that they defy systematic explanation. Indeed it is suggested that the pervasiveness of rank-size relationships is no more susceptible to theoretical explanation than the pervasiveness of the normal distribution in statistics.

Section 2 of this paper briefly classifies theoretical explanations, attempting to show that theories justifying the rank-size relationship are themselves constructed in a manner that ignores the specifics of relationships between cities. In short, the level of abstraction achieved by the theories matches that represented by the rank-size rule. Section 3 reviews the large number of studies seeking empirical correlates for the shape of city size distributions and presents a methodologically superior empirical study, concluding that none of the variables suggested can account for variations from rank-size. In the light of this, section 4 returns to the theory accounting for such distributions; it is argued that once inter-urban relations are specifically included, it becomes extremely hard to construct a theory that accounts for any particular type of city size distribution. Indeed an explanation based almost entirely on chance seems as powerful as any other. The conclusions explore implications of this for any attempts to propose the rank-size relationship as a desirable norm for the analysis of urban development.

2. EXPLANATIONS OF THE RANK-SIZE RELATIONSHIP

The rank-size relationship is:

$$P_r = P_1/r^q \qquad (1)$$

where P_r is the population of the r-th largest city. It is readily seen that this is a negative linear relationship with respect to the logarithm of population and rank:

$$\log P_r = \log P_1 - q \log r \qquad (2)$$

The rank-size rule is represented by the special case of equation (2) when q equals one. As suggested above, the rank-size relationship has come to be regarded as a norm, and therefore explanations of city size distributions have focused on this rule, as the comprehensive review by Richardson (1973) makes clear. Further, Richardson demonstrates that explanations tend to refer to the city size distribution as an equilibrium resulting from patterns of urban growth.

Rather than repeating Richardson's work, it is useful to ask to what degree the various explanations of city size distributions take into account interurban interdependencies as an important factor of urban growth. Logically the growth of a city depends on: interurban dependencies, shocks from outside the system, and impulses generated purely from within the city and its hinterland. Of these three, the second receives little attention in the city size distribution literature, and when it is considered, the transmission of external shocks via interurban links is not even discussed. Therefore the literature can be conveniently classified according to whether theoretical explanations incorporate interurban relations as a growth factor or not.

Of the thirteen explanations reviewed by Richardson, six do not discuss the possibility of relationships between cities influencing individual growth rates. Typical of this approach is the so-called law of proportionate effect or Gibrat's Law. The size of any city i may be accounted for by:

$$P_{it} = P_{io} \prod_{r=1}^{t} g_{ir} \tag{3}$$

with P_{it} being the population of i, time t, and g_{ir} being the rate of growth of i in time period r. If we assume that g_{ir} is an independent, identically distributed random variable over all i and r then the city sizes P_{it} will eventually be distributed as a lognormal distribution over i at some time t, no matter what the original distribution was at time zero. The right-hand tail of the lognormal distribution is in turn similar to the rank-size relationship.

Of the remaining seven theories, three are static equilibrium models describing city size distributions as the stable outcome of a hierarchy of urban centers. For example Beckmann and McPherson (1970) show that if the population of cities at each level of a Christaller (K = 3) central place hierarchy are randomly perturbed, a rank-size relationship can result. Although by definition a hierarchy takes account of some interurban relationships, there is little evidence of central place equilibria persisting in reality. So these approaches seem to be of limited use in studies relating to long run economic change.

Three further theories incorporate some form of interurban interdependency but in only a loose manner. One of these is Zipf's explanation discussed earlier, where the interactions are described in a manner that is too indistinct to be of any theoretical use. The other two, by Ward (1965) and Rashevsky (1943), both discuss inmigration as a source of growth. In each case, however, it is assumed that the level of inmigration solely depends on the characteristics of the destination city and not on those of the origin cities or their location. In addition there is no conception that the growth of one city implies a loss for other cities. Rather, it is assumed that the migration necessary to provide the required growth and resulting city size distributions will occur—as if conjured out of a hat.

The one approach with a well-specified conception of interaction is Richardson's extension of Fano (1969). Here the evolution of city sizes is regarded as a sum of internal growth forces and interurban interactions, summarized as:

$$\underline{P}_t^T = \underline{P}_{t-1}^T \underset{\sim}{M} \tag{4}$$

where $\underline{P}_t^T$ is a vector containing the population sizes of all N cities in the urban system: $\underline{P}_t^T = [P_{1t}, P_{2t}, P_{3t}, \ldots, P_{Nt}]$. An N by N square matrix is denoted by $\underset{\sim}{M}$, with a typical element m_{ij} representing the influence of city i on city j: a measure of spatial interaction.

It is of interest that this approach, the only one able to incorporate all three types of forces influencing a city's growth, does not guarantee a rank-size distribution. It may be shown that if the matrix of interactions does not change over time, then eventually the vector of population sizes will converge to a constant city size distribution with each city growing at the same rate: a rate determined by the largest eigenvalue of $\underset{\sim}{M}$. This stable distribution, the principal left-hand eigenvector of $\underset{\sim}{M}$, will only exhibit a rank-size relationship if the interactions m_{ij} take on particular values. If, on the other hand, the interactions of $\underset{\sim}{M}$ evolve over time, then there is no stable city size distribution that will persist unless the interactions themselves eventually stabilize. In general, interactions do change as the space-economy alters (Sheppard 1980), so even if a rank size distribution happens to exist at any one time period, t, there is no *a priori* reason to expect it to persist. Simulations by Haran and Vining (1973) indeed show that interactions changing in a manner analogous to the gravity model make the rank-size relationship unstable; it evolves towards a convex distribution.

It is also of interest that three of those four theories incorporating interurban interactions to explain growth (the exception being that of Zipf) are not well known and have not been applied by other authors. Thus it is not unreasonable to conclude that there is no well-developed theory of the rank-size relationship incorporating interurban interdependencies. Indeed, perhaps there cannot be such a theory, since very special assumptions would be necessary in order for interacting cities to evolve into a city size distribution that has a shape independent of the location of those cities. This issue will be pursued later.

A related question of some difficulty is that of identifying unambiguously whether an observed city size distribution is best represented by the rank-size relationship. Certainly an observed regularity should not be accepted without some comparison to alternative hypotheses. The difficulty is illustrated by Quandt (1964) who attempted to determine whether the rank-size relationship (a Pareto distribution of the first kind) provided a closer fit to the city size distribution for those United States cities with a population exceeding 50,000 than a series of competing distributions. This is a fairly rigorous test because of the close correspondence of these data to the rank-size rule. Of some eight alternative distributions only two were eliminated as being clearly inferior. The rank-size relationship was third best of the remaining six, but the results were sufficiently close to make any choice difficult. The two relationships that performed better were a modified Pareto distribution and the lognormal distribution:

$$P_r = \frac{1}{-q} P_1 (r + c)^{-q} \qquad (5)$$

$$p(\hat{P}) = [\hat{P}\sigma 2\Pi]^{-1} \exp\left\{-(2\sigma^2)^{-1}(\log \hat{P} - \mu)^2\right\} \qquad (6)$$

where c is a constant, $p(\hat{P})$ is the probability that a city will be of population size $\hat{P}$, and σ, μ are the standard deviation and mean of the city size distribution.

Even with the United States example there are a number of distributions that closely conform to the data. Each distribution in turn presumably has one or more theories that account for its possible existence. If interurban interactions are ignored, the lognormal distribution alone has a large number of possible stochastic processes that may generate it (Robson 1973: 36; Aitchison and Brown 1963). We are then forced to the conclusion that, in cases where a rank-size relationship seems to exist, there are many theories and hypotheses consistent with the observed data: a variety that cannot be narrowed down without further empirical and theoretical information.

3. EMPIRICAL COMPARISONS

Past Empirical Tests of Primacy

International comparisons of city size distributions rapidly reveal many cases where the rank-size relationship does not exist. These are typically classified into primate distributions, where one or two large cities dominate the distributions; convex distributions, dominated by a number of large cities; and S-shaped distributions (Figure 1). Since primacy is a problem regarded as being endemic to many Third World countries, there has been much speculation as to the reasons accounting for primacy and subsequently for other deviations from the rank-size relationship. A number of causal factors have been suggested including measures of the size of the country, its level of "economic development" and its internal and external links. A summary of the various hypotheses relating to primacy *vis-à-vis* the rank-size relationship is included in Table 1. As can be seen here, comparisons are difficult; measures of primacy and methods of hypothesis testing vary. In addition, the fundamental problem of comparing city population statistics internationally also confounds issues. Some general statements can be made, however.

First, the literature is by and large somewhat dated; there is only one study more recent than 1972. As a result the statistical techniques are rather primitive (and in many cases non-existent). In particular there has been no attempt to partial out cross-correlations between independent variables in those cases where several independent variables were tested. This makes rigorous inference difficult.

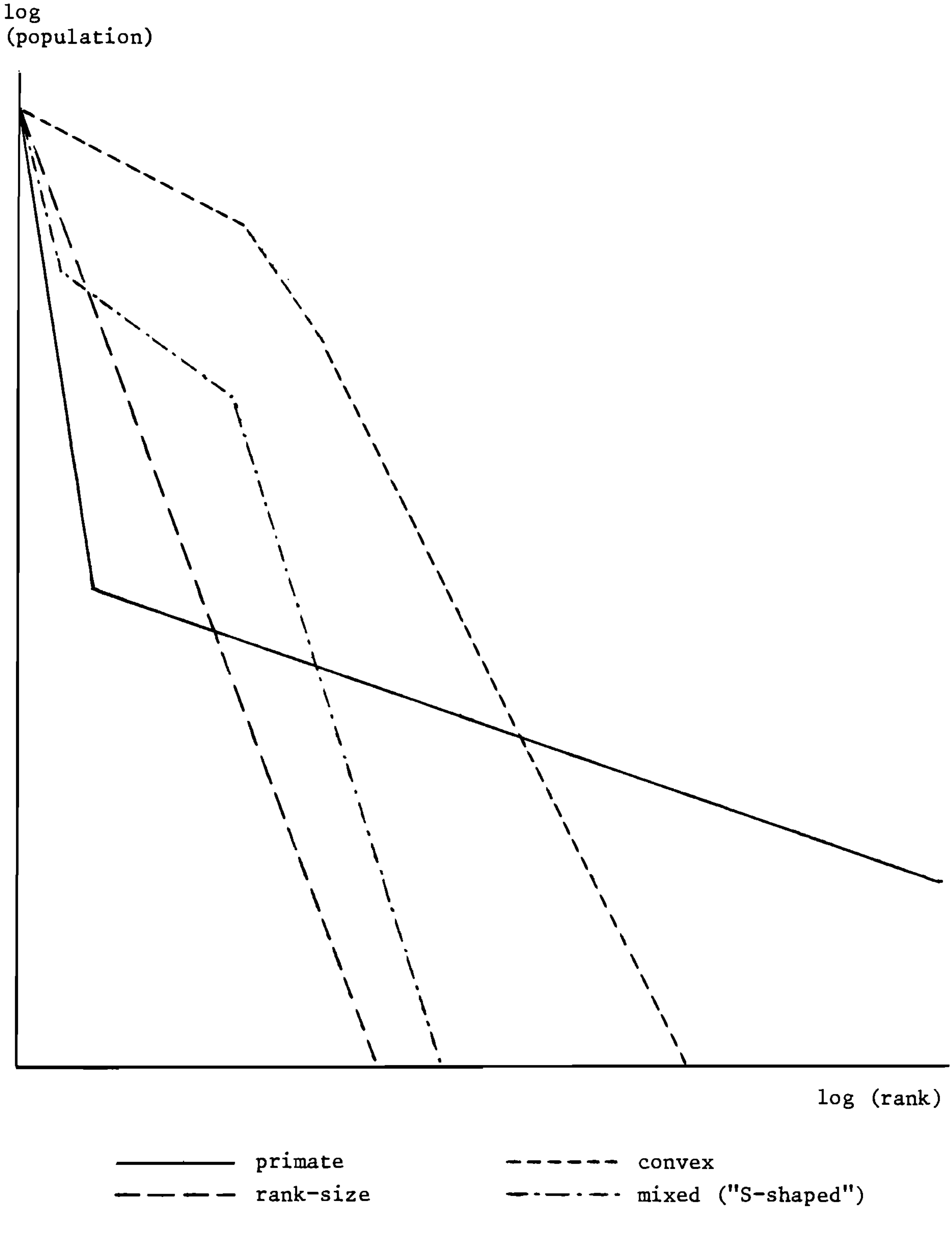

Figure 1. Alternate stylized types of city size distributions.

Table 1. Empirical correlates of city size primacy.[a]

	Author					
	Jefferson (1939)	Zipf (1949)	Berry (1961)	Stewart (1958)	Mehta (1964)	Linsky (1965)
Measure of Primacy	P_1/P_2	rank-size	visual	P_1/P_2	$P_1/\sum_{i=1}^{4} P_i$	P_1/P_2
Empirical Test	verbal	verbal	verbal/χ^2	verbal	Spearman's Rho	χ^2 (2×2 tables)
Independent Variables:						
Area (populated)			-	-	-*	-*
History of urbanization			-			
Level of "economic development"			none	+[d]		
Level of economic diversification			-	-		
Complexity of economy/ society			-			
Degree of urbanization			none (χ^2 test)	-		
Income per capita					none[f]	(-)[h]
Population size					-*	
Population growth						(+)[h]
Percent working in agriculture					none	(+)[h]
Colonial history	-[b]		+	-		(+)[h]
Energy use per capita					none	
Level of nationalism	+					
Elongation of shape of country						
External orientation				+[e]	none/+[g]	(+)[e,h]
Level of interdependence between cities	+[c]	-				

Table 1. Continued.

	Author					
	Vapnarsky (1969)	McCreevey (1971)	Harris (1971)	Berry (1971)	El-Shaks (1972)	Johnson (1980)
Measure of Primacy	none	fit to a lognormal distribution (χ^2)	visual	visual	see text	
Empirical Test	historical analysis	Pearson's correlation coefficient	verbal	verbal	regression	verbal
Independent Variables:						
Area (populated)				-[j]		
History of urbanization				-[j]		
Level of "economic development"				-[j]	inverted "U" distribution	
Level of economic diversification						
Complexity of economy/society				-[j]		
Degree of urbanization				-[j]		
Income per capita						
Population size						
Population growth						
Percent working in agriculture						
Colonial history				+		
Energy use per capita						
Level of nationalism						
Elongation of shape of country						
External orientation	+	+*[i]	+			
Level of interdependence between cities	-		-	-		+/-[k]

Notes to Table 1

*Statistically significant (0.05 level).

[a]Negative sign in the table indicates an inverse relationship noted between the variable and the level of primacy. A positive sign indicates the converse. "None" represents a test performed with no statistically significant results.

[b]Only discusses white former British colonies; suggests they are part of the British imperial urban system.

[c]This is implied in Jefferson's concept of nationalism (p. 232) as representing high national unity and low regional autonomy.

[d]Countries with self-sufficient, low density populations are regarded as lacking any urban hierarchy.

[e]Measured as: export trade as % of national product.

[f]Measured as GNP per capita.

[g]Not significant for levels of international trade, or international mail per capita, but significant for international trade in raw materials per capita (an indication of lack of economic diversification).

[h]Only significant within the sub-sample of small countries; not for the complete sample of countries.

[i]Measured as exports per capita; significant at 0.01 level.

[j]These findings represent Berry's summary of the work of Linsky and El-Shaks.

[k]Both primacy and convexity result from imbalanced interurban interdependencies (see text).

Second, measures of primacy are in almost every case somewhat crude. In particular, if equation (1) is substituted into each of these measures, it will be seen that each index of primacy depends on q. In other words rank-size relationships with different slopes will have different levels of primacy according to each of these indices. Thus it is not possible to discriminate between a country where a primate city dominates a city size distribution, which otherwise may have a low and fairly consistent negative slope, from a country exhibiting a rank-size relationship of steep slope. In short, according to each of these indices high primacy need not imply deviation from a rank-size relationship.

Third, there is little evidence of any well-specified theory being tested. Rather, the literature represents ways to evaluate likely hypotheses. As a result there is a wide range of variables considered.

Fourth, and related to the above points, the results of these tests do not exhibit a high level of internal consistency. Ten independent variables were tested more than once. Of these only four consistently produced a significant relationship in the same direction: populated area of the country, length of history of urbanization, complexity of economic life, and external orientation of the country. Of these only the first and the last were subjected to a statistical test more than once. Three of the remaining six were found to be insignificant at least once, and three exhibited both positive and negative relationships. It is of little wonder, then, that enthusiasm for such studies has waned.

Despite these problems, some general conclusions have been made. According to Berry (1964, 1971) countries that are small, have a short history of urbanization, are relatively simple in their socioeconomic and political structure, have a low level of urbanization, have strong external links, and have internal interactions that are highly polarized along certain routes can be expected to have a primate city size distribution. On the other hand, a number of authors have made a point of describing cases that contradict this conception. For example, Costello (1977:38) cites primacy in Iran, and rank-size relationships in Israel and Saudi Arabia as counter-examples; Friedman (cited in Robson 1973:37) notes that Venezuela does not fit, and McGreevey (1971) finds that many South American urban systems evolve to primacy as internal interconnections are developing. Even in Berry's original study (Berry 1961), there are examples that do not fit this stereotype at all. El Salvador, a country that has all the characteristics that Berry implies for a primate distribution, in fact exhibits a rank-size relationship. By contrast Spain, with many characteristics typical of a country that would be expected to have a rank-size relationship, exhibits primacy.

A final general trait of note is the low level of attention given to explanations that in any sense discuss internal differentiations existing within the urban system and the links between the cities. This parallels the bias in the theoretical literature mentioned above. It will be argued in section 4 that this may have unintentionally neglected a most important factor influencing the development of city sizes in an urban system.

A New Test

Due to the methodological short-comings of these previous tests of primacy, an attempt is made to more adequately test some of the hypotheses suggested. This is done by first developing an index of the deviation of a city size distribution from the rank-size relationship that is not sensitive to the slope, q. This index is then related to the independent variables suggested in these earlier studies, using a simultaneous "regression" format to reduce spurious correlations.

The index of primacy follows the approach of El-Shaks (1972) in being calculable for the entire distribution. El-Shaks's index is:

$$P = \frac{1}{N-1} \sum_{i=1}^{N-1} \left[\frac{1}{(N-i)P_i} \sum_{j=i-1}^{N} (P_i - P_j) \right] \qquad (7)$$

where N is the total number of cities in the system. However, if we suppose that the observed distribution conforms to the rank-size relationship,and we substitute $P_k = P_1 k^{-q}$ in equation (7), we obtain:

$$P = \frac{1}{N-1} \sum_{i} \left[\frac{1}{N-i} \sum_{j} \left[1 - \left(\frac{j}{i} \right)^{-q} \right] \right] \qquad (8)$$

Since j > i, P is positively related to q, and P may be high for a primate distribution or for a steep rank-size relationship; no discrimination is possible.

The index proposed here is:

$$I_N = \frac{1}{N-2} \sum_{i=1}^{N-2} \left(\frac{\log P_1 - \log P_{i+1}}{\log P_{i+1} - \log P_{i+2}} \right) \left(\frac{\log (i+2) - \log (i+1)}{\log (i+1) - \log (i)} \right) \tag{9}$$

If the substitution $P_k = P_1 k^{-q}$ is made in (9):

$$I_N = \frac{1}{N-1} \sum_{i=1}^{N-2} \left[\frac{\log P_1 - q \log (i) - \log P_1 + q \log (i+1)}{\log P_1 - q \log (i+1) - \log P_1 + q \log (i+2)} \right] \cdot$$

$$\left(\frac{\log (i+2) - \log (i+1)}{\log (i+1) - \log (i)} \right) \tag{10}$$

Cancelling out $\log P_1$ and q from the first bracketed expression and multiplying the expressions together, we have

$$I_N = \frac{1}{N-2} \sum_{i=1}^{N-2} 1 = 1.0 \tag{11}$$

Thus for a rank-size relationship the index I_N has a value of 1.0 irrespective of the slope of the relationship. If a city size distribution has more (or more severe) cases where city i's primacy over city (i+1) is greater than city (i+1)'s primacy over city (i+2) than cases for which the converse holds, then I_N will exceed one. This would suggest primacy. In distributions where the reverse is true, I_N will be less than one, suggesting convexity. Distributions where I_N is approximately equal to one will represent relatively balanced oscillations around a rank-size relationship.

Data were collected for all countries having five or more metropolitan areas with populations exceeding 100,000 according to United Nations data (United Nations 1980). Once again use of such data, even when collected by an international agency, will show great variation from country to country in terms of the way a metropolitan area is defined, the accuracy of the census, and the dates at which data were collected. Because of this any international comparison is fraught with danger. The one consolation is that such differences are not as wide for data from cities within any one country, which is the basis for the calculation of the index. For each of these 56 countries (see Appendix), I_N was calculated using equation (9) with N equaling five, and also with N equaling three. A maximum of five cities was used in order to keep the sample of countries large. Of course, this hardly reflects the full distribution of cities, but it is the largest cities that traditionally have been given closest attention (Table 1).

The independent variables are listed in Table 2. In many cases, the lack of available accurate estimates of the variable on an international basis necessitated use of an ordinal surrogate variable. The data are tabulated in the Appendix. All variables are regressed on both I_5 and I_3 for the full population of countries, using methodologies described by Leitner and Wohlschlägl (1980) that allow simultaneous use of data measured on ordinal and interval scales. Thus the hypothesis to be tested is whether international variations in the variables suggested by previous studies (Table 1) explain international differences in the degree to which a country's largest 5 (or 3) cities deviate in size from the rank-size relationship. The results are summarized in Table 3. For technical reasons of

Table 2. List of variables.*

AREA	Estimated populated area of a country (sq. km.)
POP	Number of inhabitants (per ten thousand)
POPGR	Rate of aggregate population growth (%, 1969-1970)
ENERGY	Energy consumption per capita, 1969 (kg. coal per cap.)
URBPCT	Proportion of the population living in urban areas (%)
INCCAP	Income per capita (US dollars)
AGR	Proportion of working population employed in agriculture (%)
TOTEXP	Proportion of GDP generated by exports (%)
PRIMEXP	Proportion of GDP generated by exports of primary commodities (%)
URBHIS	Length of time that the urban form of settlement has been in continuous existence [ordinal variable ranging from 1 (short history) to 5]
ELONG	The degree of elongation in the shape of the country [ordinal from 0 (rounded) to 4 (elongated)]
DEVELT	A generalized index of economic development (an ordinal ranking of component scores from the largest component in a principal components analysis of economic indicators; lowest ranks represent 'higher' development)
COLON	The colonial status of the country [nominal: 0 - never a colony of another 'advanced' country; 1 - a colony dominated by settlers from colonizing country (WHTCOL); 2 - a colony predominantly still settled by indigenous people (BLCOL)]
COMPLEX	An index of 'social and economic complexity' [ordinal from 1 (least) to 5 (most complex), scored in an attempt to take into account the concepts suggested by Berry (1961)]
INTERDP	An index of the degree of interdependency of all kinds between the cities of the national urban system [ordinal from 1 (least interdependency) to 5 (most)]
I_5, I_3	Deviations from rank size relationship (see text)

*All data for 1970, unless noted: see Appendix for sources.

Table 3. Principal regression results.

Independent variables	log I_5 "Best" regression	log I_5 "Principal Components" regression	log I_3 "Best" regression	log I_3 "Principal Components" regression
AREA			−0.301 (.07)[a]	
POP	−0.285 (.07)[a]	−0.250 (.11)		−0.173 (.28)
POPGR			−0.346 (.04)[b]	
ENERGY				
URBPCT				
INCCAP				
AGR		−0.119 (.57)		+0.021 (.89)
TOTEXP	−0.250 (.11)	−0.260 (.10)[a]	+0.127 (.60)	+0.102 (.53)
PRIMEXP				
URBHIS	+0.060 (.75)	+0.012 (.94)	+0.162 (.57)	+0.004 (.98)
ELONG	+0.056 (.70)	+0.048 (.74)	+0.087 (.53)	+0.076 (.61)
DEVELT			+0.095 (.63)	
COLON: WHTCOL	+0.066 (.74)	−0.020 (.90)	+0.306 (.17)	−0.060 (.74)
COLON: BLCOL	+0.114 (.56)		+0.277 (.20)	
COMPLEX	+0.234 (.17)			
INTERDP				
$\bar{R}^2$	0.1377 (.41)	0.1003 (.52)	0.1891 (.26)	0.0658 (.77)

SOURCE: author's computations; see Appendix.

Values in the table are standardized regression coefficients. The bracketed terms are a measure of the significance of the coefficients. These represent the probability that the null hypothesis of no relationship is true. We require these values to be less than 0.1 in order to reject the null hypothesis at a 90% confidence level. R^2 values are modified to account for the effect of varying numbers of independent variables on the degrees of freedom in the regression.

[a] Significant at the 0.05 level.

[b] Significant at the 0.01 level.

multicollinearity the full model could not be estimated. Columns one and two represent results calculated for the first five cities, whereas columns three and four are estimated with the dependent variable calculated for only the first three cities. Full details of the selection procedure are in the Appendix. It is evident that all the models fail to achieve a significant level of explanation of the dependent variable. Thus it may be concluded that the variables postulated by various authors to date almost completely fail to explain empirical deviations from the rank-size relationship using international data, at least according to the index developed here. Two particularly important caveats should be noted, however. First, the sample of countries chosen is biased significantly in favor of more highly urbanized countries in general, and highly 'developed' countries in particular, due to the limitation of having five cities with populations exceeding 100,000. It is obviously dangerous to generalize from this sample, but it does overlap significantly with the various samples of countries chosen by other authors. Second, since only the top five cities were studied, it would be misleading also to apply the results to entire city size distributions. But, once again, the studies of primacy that this attempt is designed to examine are by and large concerned with only the largest city relative to others, and the five largest cities should illustrate this relationship reasonably well. Indeed, this is why I_3 was examined in parallel with I_5.

City Sizes and Development

Several authors have investigated the relation between some index of the character of a city size distribution and a summary statistic of the level of economic development, despite the early pessimism of Berry (1961). Rosing (1966) found no relationship with respect to the rank-size rule. El-Shaks (1972) and Wheaton and Shishido (1981), however, both found an inverted U-shaped relationship between primacy and economic development. In each case the measure of primacy was different. El-Shaks used equation (7) above, whereas Wheaton and Shishido used equation (15) (which can also be interpreted as a measure of inequality). In both cases levels of primacy (or inequality) were found to be greatest for countries at an intermediate level of development, in cross-sectional studies—a result strongly analogous to the work of Williamson (1965) on inequalities in the distribution of income.

An explanation of this trend can in fact be constructed on the basis of the common view relating interaction patterns and city size distributions, well summarized by Johnson (1980) and elaborated on by Ettlinger (1981). In cases where the capital city has strong links with other countries and their urban systems, but poorly articulated links with the remainder of the national urban system, growth impulses received in the capital will not diffuse to secondary centers. Since the capital city is the locus where most growth inducing innovations develop, the result is a persistent primacy characteristic of countries with a colonial history. Several rival cities of approximately equal size develop when the national urban system consists in fact of several rival subsystems having strong interactions within, but relatively weak interactions between the subsystems. As a result a national city size distribution will be convex. However, if the interdependencies are well-developed in a "balanced" (Johnson 1980:237) manner between all pairs of cities, a rank-size relationship will evolve.

Applying these notions, it could be argued that very poorly developed countries will have low levels of interaction between cities and will thus have many autonomous subsystems, whereas "advanced" countries are highly integrated and exhibit the rank-size relationship. Intermediate countries, however, with moderately developed communications, often of an "unbalanced" nature, will be more primate in form. This argument, however, lacks a theoretical rationale that precisely relates imbalances in interactions to the existence of a rank-size relationship. The results from cross-sectional studies may not be isomorphic with a cross-temporal analysis of individual countries. In particular, the advances made by developed countries may in fact act to stop more newly developing countries from eventually following the same path in one or in many aspects of their development processes. Indeed this argument has been made with respect to the demographic transition, as well as the evolution of dualism and under-development in the Third World. The very existence of a developed group of nations with which the Third World must interact can make it all but impossible for the latter group to follow the same paths of change as the former group, without incurring severe and permanent change.

Notwithstanding such criticisms, an attempt was made to see if the inverted U-shaped trends also exist using an index measuring deviations from the rank-size relationship. The two logarithmically transformed dependent variables I_3 and I_5 used in the previously reported study were regressed against Cole's (1980) index of development (DEVELT of Table 2) using Cole's original component scores as the independent variable. A second independent variable was formed as the square of DEVELT in order to identify any U-shaped relationship, much in the manner of trend surface analysis. The results are presented in Table 4. Again what is most noticeable is the poor level of explanation; in neither case did the percent of variance explained exceed 8 percent, and neither was significant at the 0.1 level. In the case of I_3 the positive sign on the second coefficient together with a negative sign on the third coefficient does give a hint of an inverted U-shaped distribution as suggested by El-Shaks, but investigation of the scatter diagrams (Figures 2 and 3) shows little evidence of such a tendency.

The index of deviation from a rank-size relationship as a measure of primacy does not turn out to be useful empirically, and, at least using Cole's development index, El-Shaks's results have not been replicated. This once more severely calls into question the use of a rank-size relationship as any kind of norm for discussing city size distributions.

Table 4. Results of regressing rank-size regularity against development.

$$\log I_5 = 0.7549 + 0.00107\ \text{DEVELT} + 0.00102\ \text{DEVELT}^2 + E$$

(.000)* (0.918) (0.29)

$R^2 = 0.053$ $\bar{R}^2 = 0.0099$

(.302)

$$\log I_3 = 0.167 + 0.0103\ \text{DEVELT} - 0.00302\ \text{DEVELT}^2 + E$$

(.000)* (.581) (.092)*

$R^2 = 0.077$ $\bar{R}^2 = 0.036$

(.17)

*Values in brackets represent the significance level with a value of less than 0.1 considered significant.

4. CITY SIZE AND SPATIAL INTERACTION

The growth of an urban population is the sum of internal population dynamics, expressed as births, deaths, and migrations. Of these two, migration in particular has been, and is, the major force influencing variations in city sizes during the period of rapid urbanization in virtually every country. Therefore, it would be myopic to ignore these interactions in accounting for city size distributions. Migration in turn is a symptom of the spatial fluctuations of socioeconomic change, suggesting the need to draw on demoeconomic explanations.

If generalizations are to be made about the types of city size distributions that may evolve, these must, then, be couched in terms of the socioeconomic dynamics operative in a society.

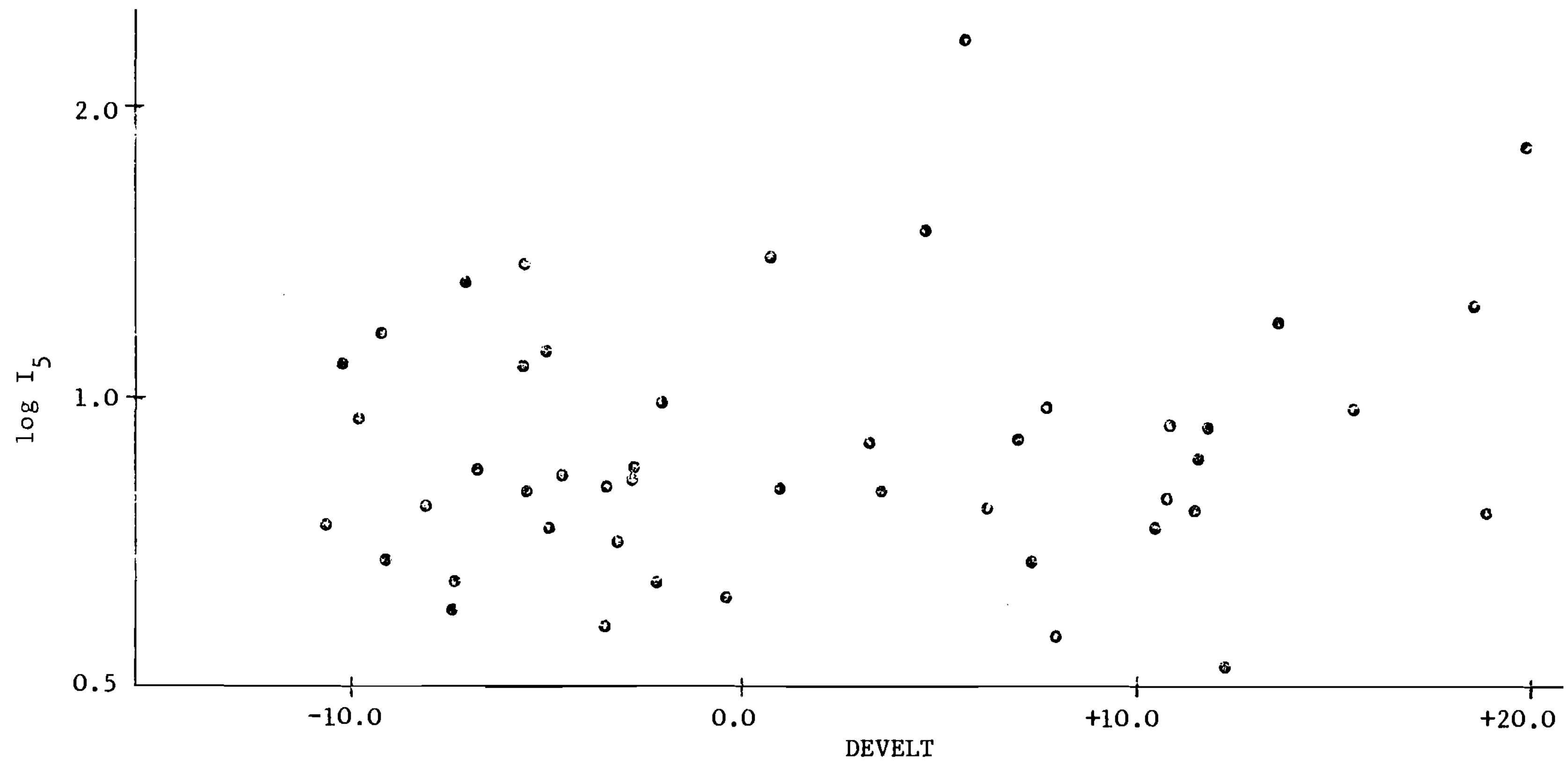

Figure 2. Scattergram of I_5 against the Index of Development.

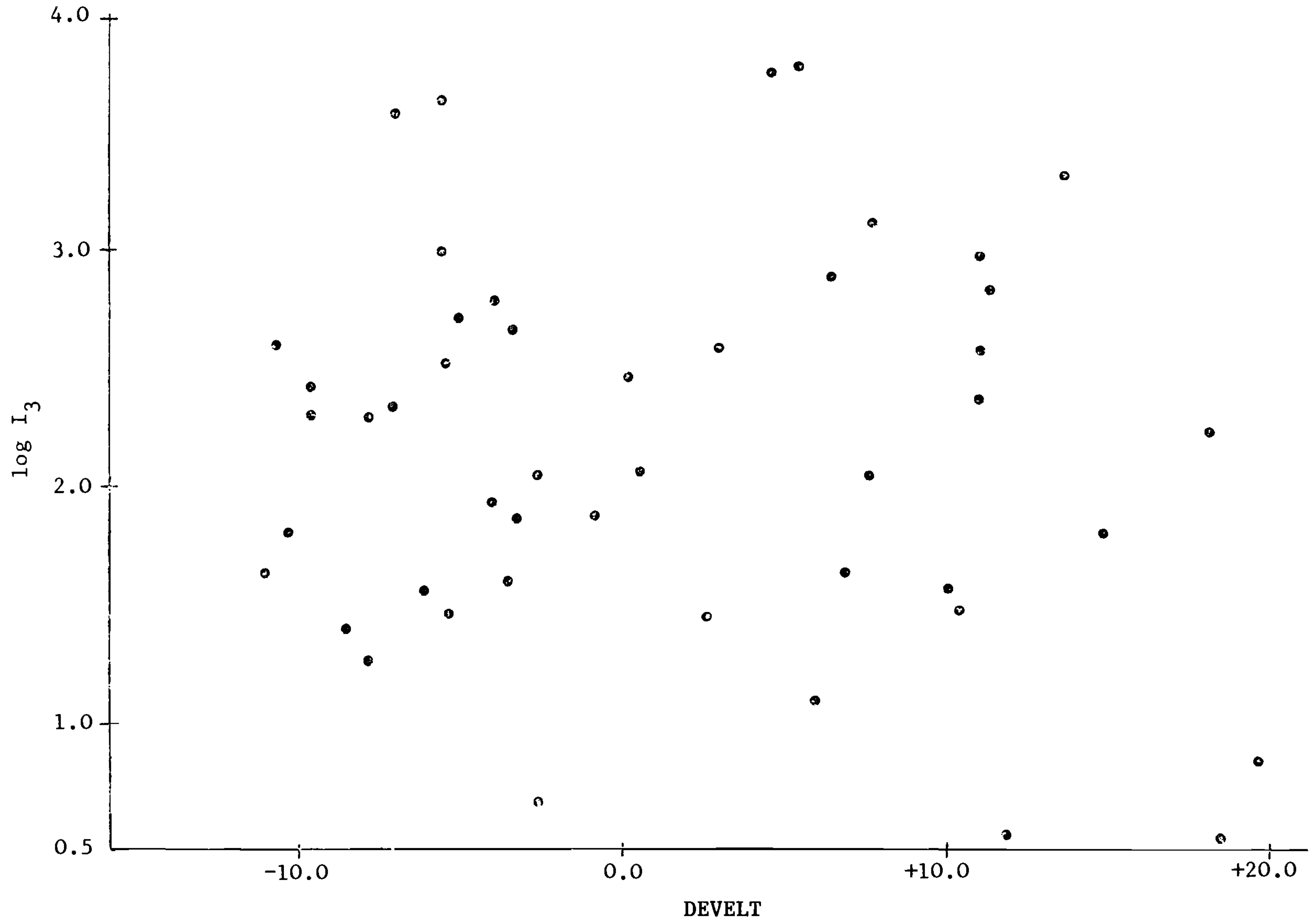

Figure 3. Scattergram of I_3 against the Index of Development.

It has been argued that these dynamics are intermediated by the spatial interdependencies between cities, a process that is not represented in city size distributions. Since the patterns of spatial development vary from country to country, it is of great interest to ask how a regularity such as the rank-size relationship can be observed in several very dissimilar countries. Two types of explanations may be conceived. First, there might exist a process that is sufficiently general to account for a pattern of city sizes irrespective of the relative location of either the cities or other socioeconomic characteristics. In this view, national factors must operate in such a way as to totally dominate internal spatial variations in interdependencies. If this were true, empirical tests using national characteristics, such as those described above, would produce high levels of explanation if the correct variables were chosen. Such general factors would then suffice to classify countries into groups with characteristic distributions. The second explanation would be that each particular type of city size distribution may be arrived at through any one of many different substantive processes. In this view, the empirical regularity does not indicate a common development process but rather is a symptom of an over-identified empirical phenomenon. In other words, a national urban system when viewed in certain ways (in this case via the city size distribution) may exhibit equifinality.

The choice between these two explanations is vital. The former would suggest a definite one-to-one relationship between spatial economic change and city size distributions, implying that this distribution could indeed be viewed as a symptom, or indicator, of how economic change is operating. However, if the latter is true this would imply the lack of a one-to-one correspondence. This would suggest in turn that the empirical regularity is a surface phenomenon only, masking very different underlying processes. It would then be dangerous to concentrate attention on the city size distribution as it would have little substantive meaning.

The purpose of this section is to examine theoretical arguments in favor of each of these possibilities in turn. These will then be posed against a third alternative: that there is no reason to expect any city size distribution to be a dominant empirical regularity.

Gibrat's Law

Berry (1971) has addressed the question of relating Gibrat's Law to spatial interactions in such a way that the former in the long run evolves independently of the precise form taken by the latter:

> Large-scale industry has tended to concentrate in a limited number of cities in a limited region that serves as a polity's industrial heartland... Such a concentration develops a self-generating momentum as complementary services and activities are established [with] increasing numbers of workers [who] more strongly pull to themselves activities seeking optimal national market access.
>
> This cumulative causation extends outwards to the hinterlands, for...the core becomes the lever for development of peripheral regions, reaching out to them for their resources...stimulating their growth...
>
> The result...is regional differentiation... Specialization, in turn, determines the entire content and direction of regional growth (Berry 1971:114).

In short, if growth impulses diffuse from some points to all other key locations in such a way as to eventually stimulate growth as strongly as at the original locations, then in the long run all places will exhibit approximately the same growth rates. This is basically the argument of neoclassical regional growth theory: strong equilibriating trends in the economy will iron out original factor differentials through a price mechanism and thus set each region (and city) on the same growth path. This result would be consistent with the requirements of Gibrat's Law, where it is assumed that each city's growth rates fluctuate around the same average in some stochastic manner. The further requirement, that this growth rate remain approximately constant through time, is also captured by the dynamic equilibrium of the neoclassical conception.

The empirical validity of this theory, however, has come under severe criticism during the last decade (Richardson 1973; Holland 1975). Summarizing a lengthy debate, it is now accepted that the types of equilibrating tendencies toward an equality of growth rates postulated by the neoclassical conception seem to be the exception rather than the rule. Even in a highly integrated capitalist economy such as the United States, persistent unevenness of development has maintained a stagnancy in some regions, while others expand. Even the recent trends toward a growth in the South and West seem more consistent with reversed, but still polarized, growth inequities than with a trend toward neoclassical equilibrium. Such inequities are only reinforced in situations where different modes of economic production attempt to coexist within one economy, exhibiting a "dualistic" or "neocolonial" relationship (Lipietz 1977).

It has been argued (Sheppard 1978, 1980) that the question of whether the spatial configuration of socioeconomic activities evolves in an equilibrating or disequilibrating manner has as much to do with the dynamic interdependency between interactions and locational patterns as it has with any initial endowment differences between locations. To ignore such dynamic relations, as has so often happened in theories of regional and urban system change (typified by the city size distribution literature), is to neglect a powerful component of any complete logic of explanation. The neoclassical model represents one view; interactions are so strongly shaped by equilibrating forces that they may be ignored. Other conceptions, however, produce different conclusions.

As a final comment on the empirical validity of Gibrat's Law, the spatio-temporal pattern of city growth rates in the United States bears examination. Given the close correspondence of the American city size distribution with the rank-size rule, and given the highly integrated nature of the economy, one might expect the assumptions of Gibrat's Law to apply here. However, the statistical independence hypothesized for city growth rates simply does not hold up. Even an examination of the early diagrams of Madden (1956) will show this, and it may be confirmed by more detailed analysis (Vining 1974). It has been characteristic of the evolution of the American urban system that individual cities will show a strong correlation between growth rates in successive decades: rates that diverge greatly from the system-wide average. Los Angeles (California) and Hudson (New York) are particulary dramatic examples. Further, there are strong spatial associations. The current trend of decline in large northeastern cities countered by stagnation in the South and growth in the West for cities of a similar size is a case in point (Berry and Dahman 1977). Thus a reliance on Gibrat's Law does not seem empirically well founded.

City Size and Migration Models

Okabe (1979b) has examined the relation between city size distributions and a non-neoclassical migration model. The results of his work are worth summarizing since they illustrate how city growth rates depend crucially on the nature of the interaction mechanism. Okabe develops a purely demographic model:

$$\dot{P}_i(t) = \alpha_i(t)P_i(t) + \sum_{j\neq i} M_{ji}(t) - \sum_{j\neq i} M_{ij}(t) \qquad (12)$$

where $P_i(t)$ is the population of city i, time t; $\dot{P}_i(t)$ is the change of this population at time t (its time derivative); $\alpha_i(t)$ is the rate of change due to natural increase; and $M_{ij}(t)$ is the number of people migrating from city i to city j at time t. Migration is modeled as a flow corresponding to the gravity model:

$$M_{ij}(t) = G_i P_i(t)^{\beta_i} P_j(t)^{\gamma_i} d_{ij}^{-K_i} \qquad (13)$$

where G_i, β_i, γ_i, and K_i are constants.

Okabe (1979b:617) shows that if $\alpha_i(t)$ is positive or negative, and if β_i equals γ_i equals 1, it is possible for the city system to evolve to a state where all cities grow at the same rate (implying persistency in the city size distribution). However, this state will not exist for more than an instant in time. Indeed it is only if β_i plus γ_i equals 1 that a state of simultaneous balanced growth can continue for all cities. This is a knife-edge equilibrium, however; it cannot be converged to by the system from any state of unequal growth rates, and the slightest deviation from equality will lead to larger and larger deviations in a cumulative causative sense.

Sheppard (1977) and Ledent (1978) have shown similar, although less complete, results. The conclusion to be drawn from this is that interactions between cities may change in such a way as to fuel ever-increasing differences in city sizes. It should be noted that Okabe's research is deterministic, whereas Gibrat's Law refers to city growth rates that deviate randomly around some constant expected value. Okabe's model may also be viewed as the expected, or mean, outcome of a stochastic process (Sidkar and Karmeshu 1981), so it is reasonable to equate the (minimal) probability of equal growth rates for cities in Okabe's work with the probability of Gibrat's Law holding for observed urban systems linked together by this type of interaction model.

Certainly gravity-like models of migration have performed as well empirically as neoclassical models. The gravity-like format also allows for consideration of vacancy- and skill-related aspects of labor markets not considered in most neoclassical models (Cordey-Hayes and Gleave 1973). Thus the choice of theory is still an open question, and the theory chosen will affect conclusions about the nature of city size distributions. This will be pursued below.

Interactions and Urban Growth

Research showing that evolving interaction patterns can bring about systematically unequal and diverging urban growth rates has damaging implications for any one-to-one identification of a city size distribution with some spatial economic process. Indeed, two fundamental implicit assumptions about the nature of interdependencies are challenged. The first is the persistence of "balanced" interactions, which has been suggested as necessary for a simple account of how rank-size relationships can evolve (Johnson 1980; Zipf 1949). Having identified the interdependencies through which growth impulses may flow, it must then be assumed that as these links change in response to the evolving urban system they would not alter in such a way as to destroy this balance. Okabe's results show that this assumption is far from inevitable. This calls into question the existence of a unique explanation of the rank-size relationship, or indeed of any city size distribution, since changing city growth rates make it difficult for the aggregate city size distribution to remain unchanging. Of course it is still possible that a city size distribution will maintain a constant shape over time, since some cities can grow, while others contract in such a way as to leave the aggregate distribution unchanged. However, the likelihood of this happening as a result of a unique type of process that is equally applicable in a number of countries seems to be relatively low. Thus rejection of this assumption would favor the explanation based on over-identification.

The second assumption commonly made concerns the feedback effects of increased interaction on urban growth. The typical implication from many views of interurban interdependencies is that they are beneficial for urban economic prosperity, but again it is far from evident that this should be true; interactions may have detrimental effects. Thus, for example, cities in the periphery of an economy may benefit little from being linked to the core metropolitan areas. Instead, skilled migrants are frequently taken from the peripheral cities. Furthermore, any flows of investment in the reverse direction can set up capital intensive activities, exploitative of local resources, the benefits of which primarily leak back to the owners of capital in the core. In such a case high levels of interdependence are far from beneficial (Stöhr and Tödtling 1979), since the feedback effects from interaction are cumulative causative rather than equilibrating. Another example of this is when the internal terms of trade between cities turn increasingly against some cities, again widening rather than reducing economic inequalities.

Such situations are characteristic of well-integrated, modern economies where integration does not guarantee that all places benefit equally, even if all are endowed with resources. It is even more characteristic, of course, of Third World economies where an increasing interpenetration of modern modes of production often leads to a dismantling of more traditional modes in a way that is destructive not only locally but also nationally. To argue, then, that primacy is curable by increasing the ease of transportation within the hinterland has proved to be far from true. The effects of such actions depend crucially on the economic and social situation within the economy.

Essentially I am arguing that solutions based on vague notions of interaction are not enough. Rather, what is needed to understand how the urban system came about (and to discuss implications of further changes) is an integration of demographic and economic factors, drawing upon those theoretical paradigms that most adequately analyze the on-going system. I would suggest that a potentially fruitful source may be found in the production-oriented approaches of the Cambridge (England) school of political economy, which maintain a strong tradition in the classical economics of Marx, Sraffa, and Ricardo (Sheppard 1980). City size distributions are just one simple aspect of the urban system and cannot be easily analyzed without taking into account the social processes and spatial configuration of the national economy.

Why the Rank-Size Rule?

The implications of the previous section suggest that since there is no one-to-one identification of urban system change and city size distributions, no particular city size distribution would be more common than any other. However, certain characteristic types, notably the rank-size relationship, have been frequently identified. I argue that this may be simply because the rank-size relationship can be arrived at from a wide range of specific situations.

This problem is approached by discussing the most reasonable guess about the distribution of an urban population among cities of different sizes that can be made. To motivate discussion, consider the initial guess that a person might make about the relative likelihood of a coin toss turning up as heads or tails. Unless provided with prior information about the existence of bias in the coin, the most reasonable guess would be to give each possibility as much chance as is reasonable of being true.

In the case of city size distributions, let p_i represent the proportion of the national urban population to be found in city i, where, summing up over all cities:

$$\sum_{i=1}^{N} p_i = 1.0 \qquad (14)$$

The universe of all possible city size distributions for N cities is the set of all possible combinations of p_i that can be conceived as being consistent with the accounting definition [equation (14)]. If we knew nothing about the urban system, the most reasonable guess would be $p_i = 1/N$ for all i, as in the coin tossing case.

This can be derived analytically by maximizing the amount of prior uncertainty we have about the situation, where uncertainty may be defined as (Tribus 1969):

$$H = -\sum_{i=1}^{N} p_i \log p_i \qquad (15)$$

If (15) is maximized subject to the constraint (14) then the solution $p_i = 1/N$ is obtained.

We do know some things about urban systems, however, and so we should rationally include this information just as we should include anything known about the bias of a coin before making our best guess as to its outcome. In particular we know that virtually every contemporary urban system has a hierarchical structure to it. Thus we would want to include a constraint, or statement of prior information, about the degree to which it is hierarchically structured. One way of measuring this would be to make a hierarchical index depend on the proportion of the total urban population in the r-th largest city p_r, weighted by the rank of that city, such that when the cities are fairly equal in size the weights give rise to a large number for the hierarchical index, whereas a steep city size distribution would give a low number.

One such index is:

$$\frac{1}{N} \sum_{r=1}^{N} p_r \ln(r) = K_1 \tag{16}$$

If all the urban population is concentrated in one city, K_1 equals 0. If it is equally spread among cities K_1 equals $N^{-2} \sum_{r=1}^{N} \ln(r)$. Values in between represent different levels of hierarchical inequality in city size, and K_1 would be chosen as a constant representing the hierarchical nature of any particular urban system.

If (15) is maximized subject to (14) and (16) we obtain the following equation representing the most reasonable guess at the size distribution of cities:

$$p_r = p_1 \, r^{\mu} \tag{17}$$

which is a restatement of the rank-size relationship [equation (1)]. In equation (17) μ must be negative because p_r equals $p_1 r^{\mu}$ which is less than p_1, and r is greater than 1. Also it can be shown that as K decreases, μ decreases, implying an increasingly steep rank-size relationship as the hierarchical index becomes stronger.

The implication to be drawn from this is that starting with only the two pieces of prior information—that the p_i sum to one (which is true by definition) and that the degree of hierarchical structure in a city size distribution may be described by equation (16)—our best guess as to the shape of the distribution is the rank-size relationship [equation (17)]. In short no specific theory is necessary to derive the rank-size relationship; rather it represents the most reasonable guess contingent on some basic prior information. This tends to support the argument that the rank-size relationship is not related to any particular process, but may be arrived at in many different ways. See also Curry (1964).

Of course equation (16) is only one way to calculate a hierarchical index. Other examples are:

$$\frac{1}{N} \sum p_r \, r = K_2 \tag{18}$$

$$\frac{1}{N} \sum r \log(p_r) = K_3 \tag{19}$$

Maximizing (15) subject to (14) and (18) yields:

$$p_r = p_1 e^{\phi(r-1)} \tag{20}$$

whereas maximizing (15) subject to (14) and (19) yields:

$$p_r = p_1 \exp\{\psi(r\ p_r^{-1} - p_1^{-1})\} \tag{21}$$

with both ϕ and ψ being negative constraints. Undoubtedly other hierarchical indices may be derived giving rise to best guesses of city size distributions. Thus from different simple starting positions one of a variety of most reasonable city size distributions can be deduced. But in each case there is no unique theory for a unique distribution, underlining the difficulty of making inferences from any city size distribution to the type of spatial socioeconomic process generating it. This once again supports the over-identification hypothesis.

The variety of possible distributions indicated above suggests a need to examine why the rank-size relationship has become the norm, about which deviations are discussed. As noted above, Quandt (1964) found it difficult to unambiguously associate the rank-size relationship with the classic empirical example of United States cities. Expanding such comparisons to the international sphere, I know of no attempt to determine whether the rank-size relationship is more common than any other shape for national urban systems. The work of Quandt and Rosing (1966) indeed suggests that any firm conclusions would be difficult. One is tempted to conclude that if researchers had started with a different transformation of population and ranks, then a different straight line might have been observed leading to a different norm. The rank-size norm cannot even be argued to be a norm of capitalist, or socialist, development patterns. In Berry's 1961 study rank-size relationships were found in only 6 of 20 western developed countries, one of two developed socialist countries, and 5 of 16 Third World countries. Thus it is difficult to find any substantive reason for choice of this yardstick other than the sociology of comparative urban research.

5. CONCLUSIONS

The implications of this review for the rank-size relationship are important. First, this distribution has patently failed to perform as an empirical norm. Observed deviations from this relationship cannot be accounted for empirically; the extent to which other empirical studies performed better than those carried out for this study may be precisely due to the fact that they did not rigorously use the rank-size relationship as a norm. Second, when spatial interactions between cities are allowed for in a dynamically evolving social system, there does not seem to be any justification for the rank-size rule on theoretical grounds. This is argued because spatial economic growth processes seem to be disequilibrating in nature. Overwhelmingly, the theoretical evidence favors explaining the rank-size relationship as being a profoundly over-identified concept. There is also little evidence to suggest that other city size distributions can be better identified with a unique set of social processes, for reasons that are not difficult to isolate. City size distributions, in only portraying restricted aspects of an urban system, provide a description that eliminates all locational and substantive socioeconomic information.

Despite this there has been, and in some restricted circles there continues to be, a fascination with city size distributions as some fundamental concept to be explained. The power of the concept must depend on being able to show a one-to-one identification with processes, but this has not been the case. A principal methodological conclusion, then, is that the rank-size relationship, and other city size distributions, should be treated as derivative concepts: patterns that depend on the particular substantive processes of urbanization and development. Comparisons of city size distributions can be all too misleading since the same pattern may be a symptom of very different situations. Thus to treat such patterns as an index of the performance of a national or sub-national economy may be dangerous.

This is not to suggest that such distributions are of no use. For example, it may be very informative to know that a society has gaps in its urban hierarchy because a certain size class of city is absent or overly abundant. However, whether or not that constitutes a problem will depend on the situation at hand. Thus, for example, a Third World country with a primate distribution may be missing intermediate cities, but it is conceivable that this might be a good thing. Increasing integration of the urban hierarchy could mean that, as a result of polarized uneven development, certain people and regions will tend to a state of persistent economic stagnation or decline. If so, then a better strategy might be to give those regions more autonomy (Stöhr and Tödtling 1979), even though this may lead to an "oddly" shaped city distribution. The principal theoretical conclusion, then, is the need to approach questions such as this from the point of view of having an accurate theoretical understanding of the processes involved, before pronouncing on the importance of desirability of certain city sizes.

The rank-size relationship then should not be treated as a norm for national settlement policies. Until we can agree on what is a desirable mode of social, political, and economic development, and unless that mode uniquely specifies a "best" city size distribution, such normative claims may do more harm than good. Better, perhaps, is to concentrate on the processes themselves, rather than on poorly identified symptoms of those processes. After all, no amount of tinkering with city-size distributions may be able to make up for the fact that the problems are caused by the nature of the socioeconomic system itself. Indeed, if tinkerings reinforce a poor social system, then they do more harm than good.

APPENDIX: EMPIRICAL STUDY OF DEVIATIONS FROM THE RANK-SIZE RELATIONSHIP

In order to minimize the considerable difficulties involved in international comparisons of city sizes, a study from the United Nations (1980) was used as a source for the dependent variable. In this study an attempt was made to adjust census data to match a common definition of a city as a continuously built-up urban area. Data for 1970 were used since that was the most recent date that corresponded closely to a national census. Fifty-five countries had five or more cities included in the UN study (which used 100,000 as its threshold population in order for a city to be included). Of these, Vietnam was eliminated since in 1970 it was subdivided. Interestingly, Vietnam's pattern was closer to a rank-size relationship than any other country. (The United States had a primate distribution since according to the UN definition of a city New York's population exceeded 18 million.) Table A1, appearing at the end of this appendix, contains the data used in this study.

Due to high multicollinearity a simultaneous regression using all 15 independent variables was not run. Indeed the determinant of the cross-product matrix equaled 0.9 multiplied by 10^{-7}, indicating extreme statistical and computational problems if the full model were used. As a result two strategies were tried. First, a large number of subsets of independent variables were selected such that less than 10 percent of the simple pairwise correlations between these exceeded 0.5, with no such correlations exceeding 0.6. Thirty-six combinations were selected and multiple regressions were performed, using the methods of Leitner and Wohlgschlägl (1980) to simultaneously regress nominal, ordinal, and interval scaled data. This necessitated subdividing the three class nominal variable COLON, into two dummy variables: BLCOL with a value of 1 if the country was a colony predominantly settled by the indigenous people and WHTCOL with a value of 1 if the country was a colony predominantly settled by the colonizers. The one combination with the largest R^2 was then selected. As a second method, a principal components analysis was performed on the independent variables. The principal components themselves could have been used as instruments for a multiple regression, avoiding multicollinearity. However, due to the dubiousness on theoretical grounds of the links between many of the independent variables and I_N, it was felt that this approach would confuse the issue. So as an alternative, individual independent variables were selected as instruments to represent those components with eigenvalues exceeding 1.0, by selecting as representative variables those with the highest loading on each component. Two other variables with distinct patterns of loadings on all 4 components were included. As a result the variables POP, AGR, TOTEXP, URBHIS, BLCOL, and ELONG were regressed on the dependent variable. In fact, this turned out to be one of the 36 combinations selected by the first method.

As discussed in the main text, two dependent variables were used: I_5, the index of deviation calculated using the largest five cities and I_3 the same index calculated for just the first three cities. The latter was also used since with I_5 the possibility existed of deviations by the largest city being masked by contrary trends shown by the smaller cities. Thus I_3 in some ways was closer to primacy as envisaged by earlier contributors to the field. In each case the distribution of I was highly positively skewed. As a result a logarithmic transformation of I was used. Each of the above two methods were performed for I_5 and then for I_3. The resulting models appear as columns one/two and three/four, respectively, in Table 3 of the text.

None of the 36 regressions performed on I_5 had a coefficient of multiple determination that was significant at a level of 0.1. Indeed, the best regression had a significance level of 0.62; a less than even chance of the model being valid under the null hypothesis. Thus, statistically speaking, the causal hypothesis would have to be rejected. Even though the relationship of the sample chosen to any hypothesized population is unclear, the results are still worth stating while noting that with only 12.78 percent of the variance explained under 49 degrees of freedom, the model performed unambiguously poorly. In considering the significance of individual regression coefficients at the 0.1 level, only POP and TOTEXP were ever significant in any of the 36 regressions. POP was significant 5 out of the 18 times it appeared; TOTEXP was significant twice out of 18 times. Both were negatively related to I_N. For POP this was expected, but for TOTEXP it was contrary to previous studies. Thus it is clear that what may make sense in terms of city size inequity in general does not apply when inequity only as a deviation from the rank-size relationship is considered. Regarding the (statistically non-significant) direction of relationships of the other variables in the 36 regressions, AREA, POP, and DEVELT were consistently negative, as expected. (DEVELT was ranked with the "advanced" countries, having a low rank.) POPGR, AGR, TOTEXP, and PRIMEXP (all negative) and ENERGY, URBPCT, INCCAP, URBHIS, COMPLEX, and INTERDP (all positive) had a direction of influence that was contrary to expectations and previous studies. Only BLCOL and WHTCOL were positive as expected, showing that a colonial history is related to primacy. But we can conclude that 10 out of the 15 variables have a counterintuitive direction, suggesting again that when primacy is measured as deviation from a rank-size relationship, the suggested hypotheses fail to stand up to empirical testing.

For the regressions on I_3, again none had a significant level of explanation overall. The highest R^2, representing 18.91 percent of variance explained, had a significance level of 0.26. AREA and POPGR were the only variables to be individually significant in the 36 regressions at the 0.1 level, each being significant only twice in 18 appearances and each having a negative relation with I_3: the former being as expected while the latter contradicted Linsky's partial result. Regarding the (statistically non-significant) direction of relation of the other variables, the signs were much less stable than for the regression on I_5. Thus URBPCT, AGR, and INTERDP all had one or two regressions where the sign was reversed from its modal direction, while URBHIS and WHTCOL (especially when BLCOL was not in the regression equation) had both approximately equal numbers of positive and negative regression coefficients. On the other hand, ENERGY, INCCAP, AGR, TOTEXP, and PRIMEXP all had the direction of influence reversed from those of the I_5 regressions, making their direction of influence more consistent with expectations. DEVELT also had a reversal of its relationship, making it contrary to expectations. COMPLEX and INTERDP were still contrary to expectations suggesting that measures of the internal economic geography of the country do not have a predictable relation to deviations from the rank-size relationship, even when taking only the first three cities into account.

In comparing these results to the principal components-based approach to defining a causal model, it may be seen that in each case this second model is significantly poorer in its level of explanation: the variance explained is 10.03 percent for I_5 and 6.58 percent for I_3. Overall, then, it can be concluded that despite the incomplete and partial nature of these tests, the poor performances provide little encouragement that a more complete study would be worthwhile. The rank-size relationship seems of little use empirically as a basis for explaining deviations towards primacy and convexity on the basis of the types of general international measures used in the literature. This points to the need for better theoretical explanations based in social dynamics. Different results might be achieved using some general measure of inequality of city sizes. However, since there are so many indices of inequity, with so little agreement as to which ones reflect which value judgments about inequity, a choice of the dependent variable in such a study could be highly contentious.

Table A1. Data used in empirical analysis.

	AREA	POP	POPGR	ENERGY	URBPCT	INCCAP	AGR	TOTEXP	PRIMEXP	URB-HIS	EL-ONG	DEV-ELT	CO-LON	COM-PLEX	INT-ERDP	log I_5	log I_3
ZAMBIA	753	418	2.8	523	31	335	69.4	58	56	1	3		2	1	1	0.449	2.458
ZAIRE	2345	2164	2.0	76	30	87	78.3	42	40	1	0	44	2	1	1	0.450	2.300
ALGERIA	596	1433	2.4	411	46	310	55.7	27	26	3	1	39	2	3	3	1.409	3.570
EGYPT	501	3333	2.5	226	42	202	54.8	14	11	5	3	33	0	3	3	1.142	1.466
MOROCCO	288	1552	2.5	191	34	202	60.6	21	18	3	3	38	0	2	3	0.748	2.361
S. AFRICA	1221	2082	2.6	2612	49	672	29.6	22	14	1	1	24	1	3	4	0.343	1.883
NIGERIA	924	5507	2.5	35	16	98	67.0	18	18	3	0	40	2	2	2	0.921	1.824
CUBA	115	847	2.0	1067	61	270	32.8	19[x]	17	1	4	23	1	3	5	1.478	2.500
MEXICO	1313	4909	3.3	1150	61	653	46.6	8	6	3	3	27	1	3	3	0.762	2.680
ARGENTINA	1827	2321	1.4	1625	80	1000	15.2	10	9	1	2	18	1	3	3	2.220	3.788
CHILE	378	886	2.1	1204	80	614	25.4	16	15	1	4	20	1	4	4	0.700	2.635
BRAZIL	4512	9339	2.9	479	57	368	43.7	8	7	1	2	25	1	4	2	1.005	0.708
COLOMBIA	569	2112	3.0	593	63	358	45.2	14	13	2	2	30	1	2	3	0.221	1.930
PERU	855	1359	2.8	618	56	293	45.5	20	19	2	3	31	1	2	2	0.689	2.762
VENEZUELA	612	1040	3.4	2024	77	781	26.2	27	27	1	1	22	1	3	3	0.692	2.058
CANADA	2494	2132	1.8	8738	76	3368	8.0	23	14	1	2	2	1	4	4	0.639	0.576
USA	7863	20488	1.3	10784	70	4289	4.0	6	2	1	1	3	1	5	5	1.367	2.241
CHINA	6398	77366	2.1	466	22	90	66.5	2[x]	1	5	1	29	0	4	2	0.484	1.572
JAPAN	372	10399	1.0	2833	72	1664	20.7	11	1	2	3	11	0	5	5	0.706	1.444
N. KOREA	121	1389	2.8	1944	50	290[+]	53.2	6[x]	5	3	2		0	3	2	1.818	1.919
S. KOREA	99	3132	2.4	650	41	245	58.0	15	6	3	2	26	0	3	2	0.366	2.060
BURMA	677	2758	2.2	54	23	113[+]	63.7	6	6	2	0	40	2	1	2	0.402	2.307
INDONESIA	2027	11409	2.2	105	18	98	70.0	13	13	2	2	45	2	1	1	1.223	2.435
MALAYSIA	330	1203	2.9	452	23	345	56.5	41	36	2	3	32	2	2	2	0.741	2.741
PHILIPPINES	300	3685	3.0	278	34	228	69.5	19	16	1	2	37	2	3	2	1.091	3.004
VIET NAM	330	3948	3.1	299	18		76.1			2	4		2	2	2	0.298	2.138
AFGHANISTAN	216	1709	2.2	26	11	83	81.5	7	6	3	1	48	2	3	1	1.135	2.585

Table A1. Continued.

	AREA	POP	POPGR	ENERGY	URBPCT	INCCAP	AGR	TOTEXP	PRIMEXP	URB-HIS	EL-ONG	DEV-ELT	CO-LON	COM-PLEX	INT-ERDP	log I_5	log I_3
BANGLADESH	144	6067	2.5	30	8	50	70.5	9	4	2	1	47	2	2	3	0.559	1.625
INDIA	3288	53986	2.5	188	20	90	67.7	4	2	3	2	41	2	3	2	0.260	1.308
IRAN	1098	2866	2.7	566	40	316	46.3	30	28	5	1	35	0	3	3	1.483	3.655
PAKISTAN	804	5351	2.8	96	28	196	70.5	8	4	3	2	43	2	2	3	0.617	1.433
IRAQ	218	944	3.1	629	58	370	46.6	36	36	5	1	34	0	2	3	0.585	2.521
SAUDI ARABIA	115	774	2.6	767	49	657	60.5	60	60	3	3	36	0	1	2	0.692	1.578
SYRIA	62	625	3.2	483	43	258	48.8	20	17	5	1		0	2	3	0.555	1.295
BULGARIA	111	849	0.8	3617	52	670[+]	42.2	22[x]	13	3	2	16	0	4	3	0.854	2.906
CZECH.	128	1433	0.5	6161	55	1524[+]	15.5	27	6	3	3	8	0	4	4	0.809	2.608
DDR	108	1706	-0.1	5677	74	2546[+]	12.4	18	2	2	2	9	0	4	4	0.658	2.373
HUNGARY	93	1032	0.4	2899	46	955[+]	25.4	37	14	3	2	14	0	4	4	1.003	3.140
POLAND	313	3253	1.0	4042	52	767[+]	38.4	19[x]	11	2	0	15	0	4	4	0.421	1.652
ROMANIA	238	2025	1.0	2695	41	384[+]	51.9	10[x]	3	3	0	19	0	4	3	1.591	3.762
SWEDEN	336	804	0.7	3218	81	3736	9.4	24	7	2	3		0	5	4	01927	2.061
UK	244	5573	0.5	5151	88	1991	2.8	23	4	2	2	7	0	5	5	0.900	2.869
ITALY	301	5387	0.7	2418	64	1591	21.1	19	5	3	3	13	0	4	4	0.237	2.063
SPAIN	505	3378	1.1	1353	55	884	33.7	17	8	3	0	17	0	3	3	0.635	1.117
TURKEY	600	3523	2.5	467	48	344	69.1	6	5	4	2	28	0	3	2	0.775	1.901
YUGOSLAVIA	256	2021	1.0	1303	35	621[+]	53.4	19	8	3	2	21	0	4	3	0.887	1.469
AUSTRIA	66	739	0.5	3001	52	1734	16.1	31	10	3	2		0	5	4	1.416	3.554
BELGIUM	31	966	0.5	5401	70	2344	4.8	40	9	2	1	4	0	5	5	0.967	1.819
FRANCE	547	5077	1.0	3514	72	2550	14.3	17	4	3	0	10	0	5	5	0.927	3.065
FRG	249	6065	0.9	4833	81	2711	9.6	22	3	2	3	5	0	5	5	1.292	3.364
NETHERLANDS	41	1303	1.3	4653	78	2233	6.4	26	13	2	0	6	0	5	5	0.075	0.589
SWITZERLAND	31	627	1.6	3218	54	2808[+]	7.4	36	3	3	1		0	5	4	0.375	2.325
AUSTRALIA	1887	1251	2.0	5230	85	2644	8.4	15	13	1	1	1	1	4	4	1.909	0.860
NEW ZEALAND	135	281	1.7	2591	81	2011	11.7	23	20	1	4		1	4	4	0.612	1.849
USSR	13440	24726	1.2	4201	57	1492[+]	31.9	4[x]	1	2	2	12	0	4	3	0.561	1.588

Table A1 (continued): data sources.

ENERGY, INCCAP, TOTEXP, PRIMEXP from United Nations (1973)

POP from United Nations (1972a)

AGR from United Nations (1972b)

URBPCT, and all city populations from United Nations (1980)

DEVELT from Cole (1980) (Only 47 of the 55 countries used here are represented in Cole's data. Thus there are some missing data, meaning correlations computed with DEVELT have lower degrees of freedom.)

Other variables were computed by the author. Area was adjusted to conform with its use in Table 1 by eliminating obviously sparsely populated areas from consideration.

Footnotes to Table of data:

+Data absent from UN statistics. These were estimated by taking national figures as quoted in the domestic currency and converting to US dollars using exchange rates given by the United Nations (1973).

xData absent from UN statistics. Figures were taken directly or indirectly from national reports issued by the Statistisches Bundesamt. Volumes from the series Statistik des Auslandes (Statistics of Foreign Countries) were used for Rumania (1976), Poland (1974), China (1979), Cuba (1975), Bulgaria (1978), North Korea (1977), and the USSR (1977), Wiesbaden, West Germany. For the German Democratic Republic the source was: Staatliches Zentralverwaltung für Statistik (1976).

REFERENCES

Aitchinson, J., and J.A.C. Brown (1963) *The Lognormal Distribution,* with Special Reference to Its Uses in Economics. Cambridge, UK: Cambridge University Press.

Beckmann, M.J., and McPherson (1970) City Size Distribution in a Central Place Hierarchy: An Alternative Approach. *Journal of Regional Science* 10:25-34.

Berry, B.J.L. (1961) City Size Distributions and Economic Development. *Economic Development and Cultural Change* 9:673-87.

Berry, B.J.L. (1964) Cities as Systems within Systems of Cities. *Papers of the Regional Science Association* 13:147-62.

Berry, B.J.L. (1971) City Size and Economic Development. In *Urbanization and National Development*, edited by L. Jakobsen and V. Prakash. Beverly Hills, California: Sage Publications.

Berry, B.J.L., and D. Dahman (1977) Population Redistribution in the United States in the 1970s. *Population and Development Review* 3:443-71.

Cole, J.P. (1980) *The Development Gap: A Spatial Analysis of World Poverty.* New York: Wiley. Page 125.

Cordey-Hayes, M., and D. Gleave (1973) Migration Movements and the Differential Growth of City Regions in England and Wales. *Regional Science Association, Papers* 33:99-123.

Costello, V.F. (1977) *Urbanization in the Middle East.* Cambridge, UK: Cambridge University Press.

Curry, L. (1964) The Random Spatial Economy: An Exploration in Settlement Theory. *Association of American Geographers, Annals* 54:138-46.

El-Shaks, S. (1972) Development, Primacy and Systems of Cities. *The Journal of Developing Areas* 7:11-36.

Ettlinger, N. (1981) Dependency and Urban Growth: A Critical Review and Reformulation of the Concepts of Primacy and Rank-Size. *Environment and Planning A* 11:1389-1400.

Fano, P. (1969) City Size Distributions and Central Places. *Regional Science Association, Papers and Proceedings* 22: 29-38.

Haran, E.G.P., and D.R. Vining, Jr. (1973) A Modified Yule-Simon Model Allowing for Inter-city Migration and Accounting for the Observed Form of the Size Distribution of Cities. *Journal of Regional Science* 13:421-38.

Harris, W.D., Jr. (1971) *The Growth of Latin American Cities.* Athens, Ohio: Ohio University Press.

Holland, S. (1975) *Capital Versus the Regions.* London: Macmillan.

Jefferson, M. (1939) The Law of the Primate City. *Geographical Review* 23:90-100.

Johnson, G.R. (1980) Rank-Size Convexity and System Integration: A View from Archeology. *Economic Geography* 56:234-47.

Ledent, J. (1978) *Stable Growth in the Non-Linear Components-of-Change Model of Interregional Population Growth and Redistribution.* RM-78-28. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Leitner, H., and H. Wohlschlågl (1980) Metrische und Ordinale Pfadanalyse: Ein Verfahren zur Testung Komplexer Kausalmodelle in der Geographie (Metric and Ordinal Path Analysis: An Introduction to Testing Complex Causal Models in Geography). *Geographische Zeitschrift* 68:81-106.

Linsky, A.S. (1965) Some Generalizations Concerning Primate Cities. *Association of American Geographers, Annals* 55: 506-13.

Lipietz, A. (1977) *Le Capital et son Éspace* (Capital and Space). Paris: Maspero.

McGreevey, W.P. (1971) A Statistical Analysis of Primacy and Lognormality in the Size Distribution of Latin American Cities, 1750-1960. In *The Urban Development of Latin America 1750-1920*, edited by R.M. Morse, with M.L. Conniff and J. Wibel. Stanford, California: Center for Latin American Studies, Stanford University.

Madden, C.H. (1956) Some Temporal Aspects of the Growth of Cities in the United States. *Economic Development and Cultural Change* 4:236-52.

Mehta, S.K. (1964) Some Demographic and Economic Correlates of Primate Cities: A Case of Re-evaluation. *Demography* 1: 136-47.

Okabe, A. (1979a) An Expected Rank-Size Rule: A Theoretical Relationship between the Rank-Size Rule and City Size Distributions. *Regional Science and Urban Economics* 9: 21-40.

Okabe, A. (1979b) Population Dynamics of Cities in a Region: Conditions for a State of Simultaneous Growth. *Environment and Planning A* 11:609-28.

Quandt, R.E. (1964) Statistical Discrimination among Alternative Hypotheses and Some Economic Regularities. *Journal of Regional Science* 5:1-23.

Rashevsky, N. (1943) Contribution to the Theory of Human Relations: Outline of a Mathematical Theory of the Size of Cities. *Psychometrika* 8:87-90.

Richardson, H.W. (1973) Theory of the Distribution of City Sizes: Review and Prospects. *Regional Studies* 7:239-51.

Robson, B. (1973) *Urban Growth: An Approach.* London: Methuen.

Rosing, K.E. (1966) A Rejection of the Zipf Model (Rank-Size Rule) in Relation to City Size. *The Professional Geographer* 18:75-82.

Sheppard, E.S. (1977) Rethinking the Nature of Urban and Regional Interdependencies. Paper presented at the meetings of the Association of American Geographers, Salt Lake City, Utah, April.

Sheppard, E.S. (1978) Spatial Interaction and Geographic Theory. In *Philosophy in Geography*, edited by S. Gale and G. Olsson. Holland: Reidel.

Sheppard, E.S. (1980) *Spatial Interaction in Dynamic Urban Systems.* WP-80-103. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Sidkar, P.K., and Karmeshu (1981) On Population Growth of Cities in a Region: A Stochastic Nonlinear Model. *Environment and Planning A* (forthcoming).

Staatliches Zentralverwaltung für Statistik (1976) *Staatliches Taschenbuch der DDR* (Statistical Handbook for the German Democratic Republic). East Berlin.

Stewart, C.T. (1958) The Size and Spacing of Cities. *Geographical Review* 48:222-45.

Stöhr, W., and F. Tödtling (1979) Spatial Equity: Some Antitheses to Current Regional Development Doctrine. In *Spatial Inequalities and Regional Development*, edited by H. Folmer and J. Oosterhaven. Boston: Martinus Nijhoff.

Tribus, M. (1969) *Rational Description, Decisions and Designs.* Oxford: Pergamon.

United Nations (1972a) *Demographic Yearbook*, vol. 24. New York: United Nations.

United Nations (1972b) *Production Yearbook*, vol. 26. New York: United Nations.

United Nations (1973) *Statistical Yearbook*, vol. 25. New York: United Nations.

United Nations (1980) *Patterns of Urban and Rural Population Growth.* New York: Department of International Economic and Social Affairs, United Nations.

Vapnarsky, C.A. (1969) On Rank-Size Distributions of Cities: An Ecological Approach. *Economic Development and Cultural Change* 17:584-95.

Vining, D.R., Jr. (1974) On the Sources of Instability in the Rank-Size Rule: Some Simple Tests of Gibrat's Law. *Geographical Analysis* 6:312-30.

Ward, B. (1965) City Structure and Interdependence. *Regional Science Association, Papers* 10:207-21.

Wheaton, W.C., and H. Shishido (1981) Urban Concentration, Agglomeration Economies and the Level of Economic Development. *Economic Development and Cultural Change* 30:17-30.

Williamson, J.G. (1965) Regional Inequality and the Process of National Development. *Economic Development and Cultural Change* 13:1-45.

Zipf, G.K. (1949) *Human Behavior and the Principle of Least Effort: An Introduction to Human Ecology.* Cambridge, Mass.: Addison Wesley.

PAPERS IN THE URBAN CHANGE SERIES

1. Piotr Korcelli, *Urban Change: An Overview of Research and Planning Issues.* WP-80-30.

2. Jacques Ledent, *Calibrating Alonso's General Theory of Movement: The Case of Interprovincial Migration Flows in Canada.* WP-80-41.

3. Peter Gordon and Jacques Ledent, *Modeling the Dynamics of a System of Metropolitan Areas: A Demoeconomic Approach.* RR-80-8. Reprinted from *Environment and Planning A* 10(1980:125-133).

4. Young Kim, *Multiregional Zero Growth Populations With Changing Rates.* WP-80-46.

5. Dimiter Philipov and Andrei Rogers, *Multistate Population Projections.* WP-80-57.

6. Marc Termote, *Migration and Commuting. A Theoretical Framework.* WP-80-69.

7. Pavel Kitsul and Dimiter Philipov, *The One-Year - Five-Year Migration Problem.* WP-80-81.

8. Boris Shmulyian, *Spatial Modeling of Urban Systems: An Entropy Approach.* CP-80-13.

9. Jacques Ledent, *Constructing Multiregional Life Tables Using Place-of-birth-specific Migration Data.* WP-80-96.

10. Eric Sheppard, *Spatial Interaction in Dynamic Urban Systems*. WP-80-103.

11. Jacques Ledent and Peter Gordon, *A Demoeconomic Model of Interregional Growth Rate Differentials*. Reprinted from *Geographical Analysis* 12(1):55-67.

12. Piotr Korcelli, *Urban Change and Spatial Interaction*. WP-80-161.

13. Morgan Thomas, *Growth and Change in Innovative Manufacturing Industries and Firms*. CP-81-5.

14. Uwe Schubert, *Environmental Quality, Abatement, and Urban Development*. CP-81-16.

15. Lars Bergman and Lennart Ohlsson, *Changes in Comparative Advantages and Paths of Structural Adjustment and Growth in Sweden, 1975-2000*. RR-81-13.

16. Jacques Ledent, *Statistical Analysis of Regional Growth: Consistent Modeling of Employment, Population, Labor Force Participation, and Unemployment*. WP-81-128.

17. Piotr Korcelli, *Migration and Urban Change*. WP-81-140.

18. Jacques Ledent, *Two Essays on Alonso's Theory of Movement*. RR-82-4. Reprinted from *Sistemi Urbani* 2/3:327-358 (1980) and *Environment and Planning A* 13:217-224 (1981).

19. Claus Schönebeck, *Sectoral Change and Interregional Mobility: A Simulation Model of Regional Demoeconomic Development in North Rhine-Westphalia*. CP-82-10.

20. Michael Wegener, *Aspects of Urban Decline: Experiments with a Multilevel Economic-Demographic Model for the Dortmund Region*. WP-82-17.

21. Tatsuhiko Kawashima and Piotr Korcelli (eds.), *Human Settlement Systems: Spatial Patterns and Trends*. CP-82-S1.