RETURNS-TO-SCALE BEHAVIOR AND MANUFACTURING AGGLOMERATION ECONOMIES IN U.S. URBAN AREAS

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Introduction

The returns to scale (RTS) parameter of urban production functions often has been used to test for the existence of agglomeration economies in urban areas. The underlying rationale is seen most clearly in a statement by Kaldor (1970), who referred to agglomeration economies as:

> Nothing else but the existence of increasing returns to scale - using that term in the broadest sense - in processing activities. These are not just the economies of large - scale production, commonly considered, but the cumulative advantages accruing from the growth of industry itself...

Thus the production function has been viewed as a convenient device for bridging the gap between the theory of agglomeration - laid down by Hoover (1948), Isard (1956), Richardson (1973), and Weber (1929) - and its measurement. Though the studies in this area recently have become much more refined, additional research has been needed in some of the more basic methodological and procedural issues connected with the empirical implementation of the production function approach. The principal objective of this study is to obtain a more accurate estimate of RTS for the manufacturing sector of urban agglomerations in the U.S. The conclusion is that the economies of agglomeration may be more complex than originally thought and it may be fruitful to examine more closely the underlying factors involved.

One of the principal shortcomings of previous studies is that almost exclusively they have been forced to use homogeneous production functions, due to the lack of information concerning capital.[1] Recent examples include studies by Moomaw (1986, 1985), Carlino (1985, 1982), Nakamura (1985), and Greytak and Blackley (1985). These have differed from the earlier genre (i.e. Nicholson, 1978; Segal, 1976; Shefer, 1973; Kawashima, 1975) in that the latest attempts have concentrated on distinguishing localization and urbanization economies from the basic scale parameter by including auxiliary variables in the production model. While most of these approaches have been quite imaginative and not without merit, if it were possible it also would be instructive to use a nonhomogeneous production function as a modeling tool to determine whether RTS change with the size of the urban agglomeration. This study uses a capital stock series developed by Fogarty and Garofalo (1980) and employs a nonhomogeneous production function, though it makes no attempt to isolate localization from urbanization economies in the process.

Background

In the literature four basic methods have been used to measure agglomeration economies. They have included (1) using city size variables in conjunction with the Hicks-neutral shift parameter of a homogeneous cross-sectional urban production function (Greytak and Blackley, 1985; Moomaw, 1985; Nakamura, 1985; Segal, 1976); (2) estimating separate homogeneous production functions for large and small cities (Schaefer, 1978, 1977; Segal, 1976) or individual cities (Carlino, 1982, 1979); (3) using nonhomogeneous urban production functions (Schaefer, 1978, 1977; Fogarty and Garofalo, 1980); and (4) employing state level data and then including urban agglomeration variables in an estimating equation (Nicholson, 1978; Beeson, 1987). Only in methods (2) and (3) are RTS estimates used to test for the existence of agglomeration economies. In this paper a combination of these two methods is implemented to determine the behavior of RTS as a function of agglomeration size in the manufacturing sector.

The theoretical basis for using a production function approach to measure agglomeration economies already has been summarized by Kaldor (1970), Carlino (1982), Greytak and Blackley (1985) and others, and will not be repeated here. Though the method is theoretically supportable, its empirical implementation has been subject to several limitations: (1) The choice of production function usually has been limited to homogeneous forms, though several studies have shown directly or have implied that the parameters of the production function (especially RTS) may change with city size. (2) Studies of U.S. SMSAs have had to resort to using one-factor models such as the well known Dhrymes variant of the CES function (Carlino

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1985, 1982; Shefer, 1973), or a variation of the Cobb-Douglas function (Moomaw, 1986, 1985) that does not use direct information on capital at all, but infers it by subtracting labor payroll from value added.[2] (3) Measurement errors or omission of variables errors related to biased or missing capital data may inflict an uncertain amount of bias on results. Studies that have attempted to decompose RTS into localization and urbanization economies face the additional problem of collinearity among most of the auxiliary variables that usually are incorporated into the estimating equation. Only in studies by Moomaw (1986, 1981) have any of these econometric problems been addressed adequately.

In the presence of such potential shortcomings, when SMSA-level capital data are unavailable a better route would seem to be that taken by Nicholson (1978), or more recently by Beeson (1987). In these studies state level data were used to estimate either cross-section (Nicholson) or time-series (Beeson) production functions, and then measures of urbanization within a state were used to capture potential agglomeration effects. A disadvantage of this approach is that the study becomes essentially regional in nature, rather than urban, and therefore is not able to measure agglomeration economies directly. In the absence of capital, the investigator is left with a choice between an indirect measure and a direct one that potentially is biased.

A capital series for urban areas (SMSAs) was available for this study and therefore some of the common pitfalls could be avoided. One major problem, choice of functional form, was solved in an earlier report (Duffy, 1986) using the same data base. By applying the statistical techniques of Pesaran and Deaton (1974) and Davidson and MacKinnon (1981) it was determined that the most appropriate urban-level manufacturing production function is one that incorporates nonhomogeneity, with elasticity of substitution (EOS) being a relatively minor factor. The results pointed to the use of the Ringstad (1974) and Vinod (1972) specifications that have the properties of constant EOS and nonhomogeneity. They also have unique RTS functions that together allow further insight into the nature and measurement of manufacturing agglomeration economies in the U.S.

Data Sources and Procedure

Data:

The observations consist of labor, capital, and output for the manufacturing sector for the years 1975, 1976 and 1977 for 49 of the largest U.S. SMSAs. During this period real GNP changed by -1.2 percent in 1975, +5.4 percent in 1976, and +5.5 percent in 1977, so that there was an overall economic expansion in the U.S. For labor and output, the data were obtained from the Census/Survey of Manufacturers, using man-hours of production workers for labor and value added for output. Table I lists the sample SMSAs and their average real value added in the manufacturing sector for the three years of the study. Since value added was in current dollars it was converted to real dollars by using an appropriate deflator, namely the producer price index for all industrial commodities, obtained from the U.S. Statistical Abstract. There was no attempt to adjust the labor inputs for quality differences or to include a labor composition variable in the production functions. Both Henderson (1982) and Sveikauskas (1975) found that labor quality indices were not statistically significant in their urban production/productivity models.

Capital inputs were measured by capital stock and were provided by Fogarty and Garofalo (1982). They utilized the perpetual inventory/book value method of estimation, which is outlined as follows: First, a 50 year investment series for the manufacturing sector of each SMSA, called the 'built-up' series, was derived for the years 1904-1953. For some early years this was obtained by apportioning investment in each state among its SMSAs on the basis of the percentage of total state value added in the SMSA. Discard and depreciation functions were applied to the gross investment series to account for obsolescence and depreciation.

Census book value of plant and equipment for 1957 were used as benchmarks to adjust the built-up series. Capital stock in any one year was obtained by summing the undiscarded, undepreciated investments of previous years. Since the pre-1954 investment series consisted of estimates derived from national data, while the post 1953 series used direct survey data, the 1975-1977 estimates used in this study presumably are the least biased of the 1957-1977 capital stock series of Fogarty and Garofalo. The use of the stock rather than the flow concept can be justified on the basis of early studies by Diwan (1965) and Lovell (1968) and more recently by Greytak and Blackley (1985). They each determined that capacity utilization adjustments did not alter production function estimates significantly.

Production Functions:

As indicated above from a previous study (Duffy, 1986), statistical tests have shown that nonhomogeneity is a better representation of the production characteristics of this sample than is homogeneity. For this reason, two nonhomogeneous forms of the production function developed by Ringstad (1974) and Vinod (1972) were estimated, along with the homogeneous Cobb-Douglas function. The homothetic Ringstad function (Equation 1) has a unitary elasticity of substitution (EOS) and possesses a unique and useful RTS function. As shown in Equation 2, RTS are a quadratic function of output, allowing for the possibility of 'turning points', i.e. maxima and minima.

$$\ln Q + c_0 Q + c_1(\ln Q)^2 = d_0 + d_1 \ln (K/L) + d_2 \ln L \quad (1)$$

$$RTS = d_2/(1 + c_0 Q + 2c_1 \ln Q) \quad (2)$$

where

K = capital
L = labor
Q = output

Because of computational difficulties in estimating the Ringstad production function, requiring an iterative maximum likelihood procedure (Zellner and Revankar, 1969), a second simpler nonhomogeneous specification also was used. This is the Vinod form (Equation 3) which is not homothetic and which possesses a nearly constant EOS.[3] As shown in Equation 4, RTS for the Vinod function depend on both of the inputs, capital and labor. Since output is closely correlated with the factors of production,

$$\ln Q = b_0 + b_1 \ln K + b_2 \ln L + b_3(\ln K)(\ln L) \quad (3)$$

$$RTS = b_1 + b_2 + b_3(\ln K + \ln L) \quad (4)$$

and because this sample has a rather large overall variation in output, (Table 1), the Vinod RTS tends to exhibit monotonicity with respect to output, except for the smallest cities in the sample. The Cobb-Douglas function (Equation 5) has received much attention in the literature. Its properties

Table 1

Classification of Selected SMSAs, by Value of Output*

SMSA	Output ($ billion)	SMSA	Output ($ billion)
Erie	1.2	Atlanta	3.5
Tulsa	1.2	Kansas City	3.6
Lancaster	1.3	Greensboro	3.7
Tampa	1.4	Louisville	3.9
Miami	1.5	Seattle	3.9
New Orleans	1.5	Buffalo	4.0
San Bernardino	1.5	Anaheim	4.4
Nashville	1.6	Baltimore	4.7
Reading	1.6	San Jose	4.7
Canton	1.6	Cincinnati	5.0
Birmingham	1.6	Minneapolis	5.5
Richmond	1.7	Milwaukee	5.7
Akron	1.8	San Francisco	5.7
Memphis	1.8	Rochester	6.1
Grand Raphids	1.9	Pittsburgh	6.3
Jersey City	1.9	Dallas	6.7
San Diego	1.9	Newark, NJ	6.9
Phoenix	2.1	St. Louis	7.2
Allentown	2.4	Cleveland	7.2
Columbus, OH	2.5	Philadelphia	11.7
Denver	2.5	Detroit	14.8
Portland, OR	2.5	New York	17.0
Youngstown	2.5	Los Angeles	21.1
Dayton	2.6	Chicago	23.7
Indianapolis	3.4		

*Output is an average of real value added for the years 1975, 1976 and 1977.

include an EOS of unity

$$\ln (Q/L) = a_0 + a_{11}n\ (K/L) + a_{21}n\ L \quad (5)$$

and a constant RTS of $1+a_2$. This is included for purposes of comparison since several previous studies have used such a specification, as detailed above.

Testing For Separate Production Functions

Following the approaches of Segal and Schaefer, an F-test was used to determine if separate production functions are warranted for different size ranges of output. Since several partitions of the sample may indicate the necessity of separate production functions, the demarcation points selected should produce the highest significant F-statistic, given by:

$$F = \frac{(RRSS-URSS)/k}{URSS/(n-ik)} \quad (6)$$

where
RRSS = restricted residual sum-of-squares
URSS = unrestricted residual sum-of-squares
k = number of estimated parameters
n = total number of observations
i = the number of separate functions tested

The F-test assumes that there is neither contemporaneous correlation nor heteroscedasticity.

After trying a two-group and a three-group partition of the sample, it was decided to use three groups for all three production functions. The F-statistic tended to be larger for three groups than for two groups, as expected, since there was one less restriction. In order to reduce the computational burden the demarcation points tested for the Cobb Douglas and Vinod functions consisted only of integer values of the dependent variable, value added. However, the F-test was used to determine the appropriate demarcation points only for the Cobb-Douglas and Vinod functions. Because the Ringstad function requires a long and arduous estimation procedure it was necessary first to select a single set of demarcation points arbitrarily, and then apply the F-test to determine their validity.

Empirical Results

The results of the F-test for the Cobb-Douglas function indicated optimum demarcation points of \$4 and \$7 billion. This partition produced the highest significant value of the F-statistic, 28.2, compared to a critical value of 3.78 (0.01 level of significance). The production function estimates for the individual groups and the overall sample are shown in Table 2. The rather low R^2 statistics for three of the four categories, including the overall sample, suggest that the Cobb-Douglas function does not provide a very good representation of the existing production structure. From the smallest to the largest sub-group the RTS estimates are 1.06, 0.42, and 0.93 with t-statistics of 1.2, 7.0, and 2.0, respectively. At the 0.05 level the null hypothesis of unitary RTS was not rejected for the smallest cities and rejected for the two larger city categories. The usefulness of these results is minimized by the poor overall explanatory power of the function.

The F-statistic for the Vinod function indicated that the optimum demarcation points were at \$2 and \$6 billion value added. With this partition the F-statistic attained its highest value, 29.6, compared to a critical value of 3.32 (0.01 level of significance). The production function estimates are reported in Table 3. Because multicollinearity may be a problem in Vinod production functions, the correlation between capital and labor also is reported. For the medium-sized cities multicollinearity seem to be present. This was indicated by the high R^2 and the absence of

Table 2
Cobb-Douglas Production Function Estimates
of City Output (t-statistics in parentheses)*

Output \$Billion	a_0	a_1	a_2	n	R^{-2}	σ^2	RTS
All Q	1.84(10.0)[a]	.38(6.7)[b]	.04(2.3)[d]	147	.25	.0258	1.042
Q < 4	1.71(5.6)[a]	.39(5.6)[b]	.06(1.2)	90	.25	.0201	1.06
4 < Q >7	5.79(10.8)[a]	.20(2.4)[b]	-.58(-7.0)[b]	36	.64	.0147	.42
Q > 7	3.28(9.9)[a]	.09(1.2)	-.07(2.0)[d]	21	.26	.0047	.93

*a - significant at 0.01 level, two-tail test
b - significant at 0.01 level, one-tail test
d - significant at 0.05 level, one-tail test

Table 3
Vinod Production Function Estimates of City Output
(t-statistics in parantheses)*

Output $Billion	b_0	b_1	b_2	b_3	n	R^{-2}	σ^2	ρ^{kl}
All Q	-.70(0.8)	.67(5.8)[a]	1.19(6.2)[a]	-.06(2.9)[a]	147	.96	.0245	.91
Q < 2	-20.40(2.1)[c]	3.81(2.7)[a]	5.70(2.6)[a]	-.78(2.4)[c]	51	.63	.0110	.37
2 < Q >6	4.61(0.8)	-.10(0.1)	.43(0.4)	.05(0.4)	63	.82	.0195	.84
Q > 6	32.1(10.8)[a]	-3.09(8.9)[a]	-3.91(8.3)[a]	.52(9.7)[a]	33	.92	.0059	.68

*a - significant at 0.01 level, two-tail test
c - significant at 0.05 level, two-tail test

significant coefficients. It also was noted that the R^2 for the under-$2 billion category was significantly lower than those for the other groups. One explanation of this recurring phenomenon may be that the smaller cities in the sample were more diverse than the cities in the other categories. In that case, a single production function never could adequately describe all production within the group, even though there were 51 observations. Above $2 billion value added the observations were much more widely scattered, leading to a much better 'fit'.

The RTS estimates for the Vinod function are plotted in Figure 1. There appears to be a distinct cyclical trend - RTS first decrease and then increase sharply to approximately unity. In the third sub-group RTS begin quite low and increase to a maximum of about 1.75. With the exception of the second group, there clearly are some questionable individual magnitudes of RTS. It is unlikely that any city could exist with an RTS close to zero or 1.7,

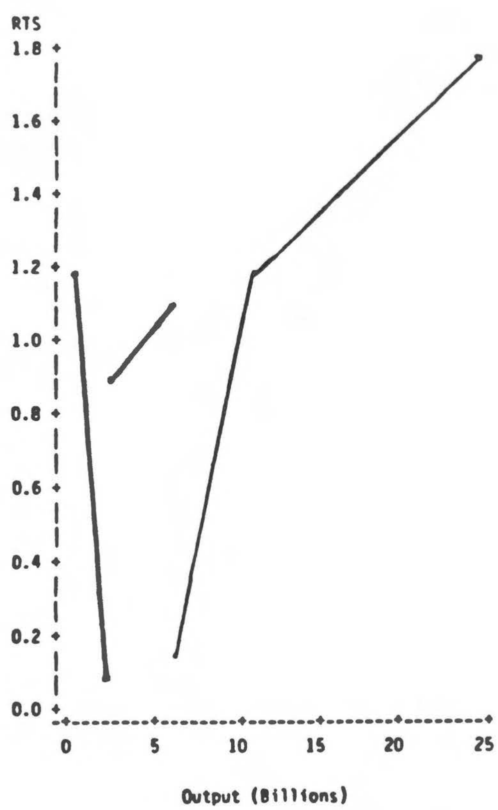

Figure 1. RTS, Vinod Production Function

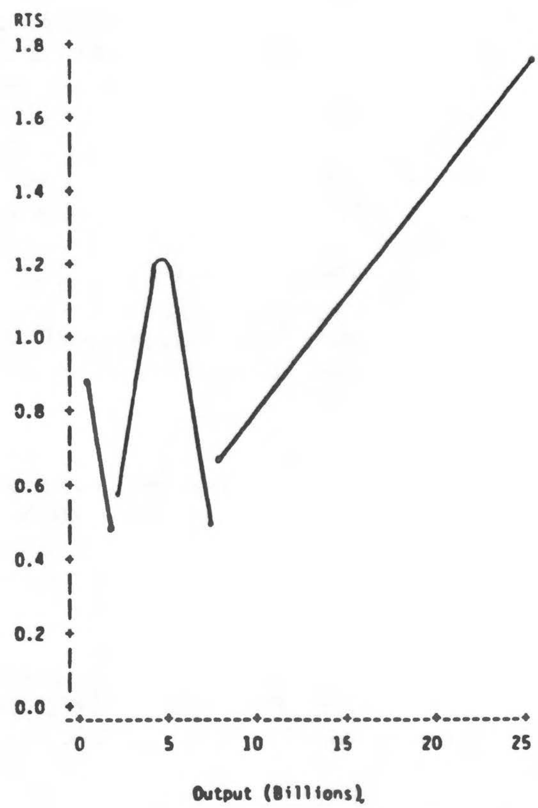

Figure 2. RTS, Ringstad Production Function

values found in the first and third groups respectively. In the case of the small-city group there probably is a connection between the unlikely values of RTS and the relatively low R^2. Another important feature of this group is the low correlation between capital and labor (0.37). It is likely that there is much less industrial diversity within each city, with each one characterized by a very distinct capital/labor ratio.

The foregoing discussion suggests either that the Vinod function is an inaccurate representation or that a different interpretation of the RTS estimate is necessary. On the basis of the high R^2 statistics for three of the four groupings, (Table 3), and the verification of the suitability of the nonhomogeneous function in the study referred to above, it would seem that the former statement is not correct. If a different interpretation is required it may be the following: the absolute levels of RTS are not as important as the relative levels. Thus there should be more concern with the direction of change, and this is easily discernible in alternate periods of decreasing, increasing, decreasing and then increasing RTS.

Further analysis with the Ringstad function leads to a similar conclusion. Demarcation points for the Ringstad function arbitrarily were set at \$2 and \$7.6 billion value added. These were selected because a scatter diagram of the output data showed definite 'breaks' at these points. The calculated F-statistic of 2,133 was significant at the 0.01 level. As shown in Table 4, all coefficients were significant at the 0.01 level and the R^2 was very high in all cases, except for the under-\$2 billion category. The RTS behavior was remarkably similar to that of the Vinod function, Figure 2. RTS decrease, increase, decrease and increase as output expands. The quadratic nature of the RTS function is seen in the middle grouping ($2 < Q < 7.6$) in which RTS exhibit a parabolic behavior, reaching a maximum at approximately $Q = 5$ before falling off. The group estimates of RTS also are consistent with each other. That is, the three groups can be spliced together almost perfectly to produce a nearly continuous graph. As in the case of the Vinod function, it appears that a 'relative' interpretation of RTS behavior may be more realistic than an 'absolute' interpretation.

Interpretation of Results

In order to place these results into perspective it is necessary first to point out fundamental differences between this and earlier studies. Apart from using an urban capital series and the more flexible forms of the production function that it allowed, there are some interrelated aspects of the study that potentially are controversial. These concern (1) the level of aggregation used, (2) its implications for the interpretation of the RTS parameter estimates vis-a-vis agglomeration economies, and (3) the rationale for not placing agglomeration economies into an external, rather than internal, scale economy framework.

At first glance the level of aggregation seemingly would dictate how the estimates of RTS should be interpreted. As a point of reference the only comparable studies that used the same level of aggregation were those of Shefer (1973) and Nicholson (1978). To Shefer, increasing RTS meant the existence of 'urbanization' economies, while Nicholson merely labeled them 'urban agglomeration' economies. Since there was no attempt here to decompose RTS into urbanization and localization economies, and neither was 'controlled' for in any statistical sense, the safest interpretation of these results probably is that of Nicholson. The interpretation by Shefer did not follow even the spirit of the original definition of urbanization economies given by Hoover who considered them to be related not only to the size of the manufacturing sector, but to the size of all sectors.

It would be tenuous at best to conclude that there are internal scale, localization, clustering[4], or urbanization

Table 4
Ringstad Production Function Estimates of City Output
(t-statistics in parentheses)*

Output \$Billion	c_0	c_1	d_0	d_1	d_2	n	r^2	σ^2
All Q	.000022	-.022	2.07(18.9)	.25(8.2)	.80(62.0)	147	.96	.0134
Q < 2	.000200	-.078	2.85(34.6)	.04(4.3)	.11(7.4)	51	.50	.0004
2 < Q >6	.000034	-.067	3.64(384.6)	.01(4.1)	.03(21.1)	81	.85	.00002
Q > 6	-.000010	-.030	4.79(36.7)	.70(4.5)	.26(8.5)	15	.97	.0004

*All reported t-statistics are significant at the 0.01 level. For the left side parameters c_0 and c_1, it is not possible to compute exact t-statistics.

economies to any specific degree. Most likely, each of these is present to some extent, as several studies have shown, though their precise influence on the derived RTS can not be determined. If there were a direct linear relation between any of these types of agglomeration economies and the size of the overall agglomeration further speculation might be fruitful, but that has not been proven. A complicating factor is that the industry mix is haphazard across regions, due to the principle of comparative advantage.

Regardless of the level of aggregation, since a straightforward production function approach is used here there is no explicit vehicle for measuring what sometimes are called 'external' effects. Any 'external' economies are assumed to be captured by the internal scale parameter (i.e., RTS). Is this justifiable? Based on a recent study by Meyer (1977), the answer is "Yes." In his effort to clarify the concept of agglomeration economies Meyer states:

> once expansion of an industry has led to external economies urban growth resulting from expansion of local industry may not necessarily be due to external economies, although localization economies will be present.

He then went on to give two examples in which

> localization economies exist but there are no external economies so long as the low cost of production in the agglomeration is mediated through the market mechanism....

and concluded that

> urban growth can be based on industrial linkage without the presence of external economies.

He was very critical of using the term 'external economies' in the context of agglomeration economies because he considered it to be "so imprecise as to be meaningless." He found that most examples of external economies for industrial firms were quickly internalized by the market, so that a more appropriate way of thinking about urban agglomeration economies is as economies of scale, internal to the production function. Thus he substantiated the view that the RTS parameter in a macro/urban production function can be a useful device for measuring the extent of agglomeration economies.

Conclusion

For a long time economists have assumed that there were efficiency advantages that accrue to firms located in cities. What else could explain the historical increase in numbers of jobs and people in urban areas? The purpose of this study, and of several previous studies, was to quantify the extent of these efficiency advantages, or agglomeration economies, from the industrial point of view. Until now, however, data limitations have not allowed detailed appraisal of the changing nature of agglomeration economies with respect to differences in city size.

Using a conventional production function approach, and couching the measurement problem in terms of the identification of scale economies, a startling result was obtained: Returns to scale were seen to be sinusoidal in nature, rather than constant, as previously thought. Only one other study has hinted at the possibility of such a phenomenon. Schaefer (1977) interpreted his results in terms of an urban hierarchy after he arbitrarily arranged his sample into seven layers, based on city size. As shown in his Table 2, RTS were variable and also exhibited a sinusoidal pattern, just as they did in this study.

An obvious implication of such behavior in both cases is that there may exist not one, but two, threshold sizes that a city must reach before 'taking off'. On the other hand, this study, unlike those of Carlino and Kawashima, purposefully avoids the temptation to postulate an 'optimal' city size, since the natural diversity of cities almost certainly precludes such vain speculation. Instead, it is concluded that there seem to be certain empirical regularities associated with efficiency advantages of a cyclical nature in our system of cities.

Admittedly, questions of causality remain unanswered at this point. The research suggests, however, that economies of agglomeration may be more complex than originally thought and that it may be fruitful for urban economists to examine more closely some of the underlying factors involved. The complex interaction of size-adjustable factors related to agglomeration must be responsible for the surprising results obtained here. The identification and quantification of these factors appears to be a good area for future research.

Notes

[1]The few exceptions have been very limited in scope. Fogarty and Garofalo (1980) obtained RTS estimates for two cities, Philadelphia and Pittsburgh in a time-series study that used a Vinod production function, while Schaefer (1978) investigated urban areas in Saskatchewan using a translog production function.

[2]Three non-U.S. studies have used direct capital data - Schaefer (1979), Nakamura (1985), and Henderson (1986). However, only Schaefer eventually employed a nonhomogeneous production function. Segal (1976), in a study of U.S. SMSAs

used direct capital data but his collection method and results were severely criticized by both Moomaw (1981) and Fogarty and Garofalo (1980). Greytak and Blackley (1985) used firm level capital data for industries in the Cincinnati SMSA.

[3]Some authors have made the mistake of labeling this a 'VES' production function. However, the variation in the EOS is invariably never more than 1% - not great enough, in my opinion, to warrant such a designation.

[4]The term 'clustering economies' is used to refer to agglomeration economies that arise because of industry mix. Henderson (1986) attempted to empirically measure the extent of cluster economies, but without much success.

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