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REGIONAL EFFICIENCIES OF BUILDING SECTOR RESEARCH IN SWEDEN: AN INTRODUCTION

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ABSTRACT. *This study examines the efficiency of institutions of higher education performing research in the building sector in Sweden. Institutions are aggregated to regions and inputs of expenditures and labor are compared to outputs in the form of publications. This preliminary and exploratory analysis suggests that institutions of the urban coastal and the newer northern regions are relatively more efficient than traditional institutions typical of interior regions. These highly preliminary findings, although quite speculative, are illustrative of the potential usefulness of DEA findings for measurement of the difficult but centrally important research productivity area.*

INTRODUCTION

Research is a central element in the global economy of the late Twentieth Century. Industry, government, and nonprofit organizations recognize the fundamental role of research in modern society. Among the traditional definitions of research—basic, development, and applied—the most difficult to measure is basic research (Haynes and Stough, 1988). However, without basic research, the scientific principles that drive innovation in development and application would not become the background for a continuous stream of new activity. The difficulty of measuring research productivity, that is, the output of research, is increasingly difficult as one moves from applied research toward basic research. Clearly, increasing productivity in all levels of research is essential to the rapid pace of development in the post-industrial economy.

Basic research is dominated by public sector support often in the context of institutions and centers within a higher education framework. In the United States, for example, it is estimated that 80% of all federally funded basic research in science and engineering is done within the context of institutions of higher education (Haynes and Stough, 1986). Applied research and

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development has a major private sector-industrial component. Given our increased dependence on research the management of research productivity is essential.

This paper is the beginning of a first step toward development of research productivity management. In order to manage research productivity it is necessary to measure it. Like any other productivity process it is necessary to specify the set of inputs required and the set of outputs desired. The relationship between inputs and outputs is the production function. In classical economic terms, a set of inputs are combined to produce an output. Traditionally, the estimation of this relationship has required a specification of the way these inputs are combined and the level of output created. With a set of observations of this input to output relationship an average production function is estimated. Given the variety of ways that these inputs could be combined it is necessary to specify a combinational rule for estimating the "form" of the function.

The difficulty we have in research productivity analysis is that we do not know the actual way in which the inputs are combined to produce an output. Further there may be more than one output, that is, patents, publications, new researchers, and so forth. This problem of multiple inputs that are combined together in either an unknown or changing way to produce multiple outputs is typical of many manufacturing and almost all service sector activity. Further, not all inputs and outputs can be reduced to a single metric such as a monetary measure. To assume a single output relationship, as in a Cobb-Douglas or Translog production function, or to prespecify a single metric for all inputs and outputs seems a highly questionable procedure unless a great deal is already known about the process or unless the circumstances are highly constrained and very stable. Further, after these assumptions are made and this econometric estimation is finished we will have estimated the production function (input-output combination) of the average research producer. This result is a consequence of our dependence on statistical regression (averaging) methodology. We will not know the production function of the most efficient research producer, that is, the research units we would like to emulate to increase productivity, or the least efficient research producers, that is, those whose pattern of resources use (inputs) and outputs generation we would like to avoid.

We have significant literature on the problems of estimating production functions using classical econometrics with respect to higher education. On the other hand, Data Envelopment Analysis (DEA) has been developed explicitly for analyzing situations of multiple inputs and multiple outputs and has been implemented for the service sector in general and for educational institutes in particular (Rhodes, 1978; Charnes, Cooper & Rhodes, 1978; Bessent, Bessent, Elam & Long, 1984; Jennegren and Obel, 1985). Using this mathematical programming methodology and its incorporation of the ratio definition of efficiency we illustrate the assessment of building sector research productivity by institutions of higher education in Sweden.

This study was stimulated by an initiative of the Swedish government which in the early 1980s began stimulating research on infrastructure under the term building sector. This support activity recognized institutions of higher education in six major regions of the country and provided resources to expand research in this important area. Such expansion was a recognition of the central role that infrastructure, particularly "smart" infrastructure, will play in a restructured knowledge intensive economy of the Twenty-First Century. As a consequence support for this evaluation activity as well as essential information on input variables was made accessible. However, the development of output assessments as well as their eventual integration was a central decision activity of the senior author and is discussed in some detail below.

We begin with a discussion of research output and how that is measured in this study. This is followed by a review of research inputs. Issues associated with measures of efficiency are then outlined. Results of the DEA by regional institutions are presented prior to a concluding statement. Although limited in scope it will be clear that this is a first step that can use further elaboration and extension with respect to inputs and outputs and with respect to the management diagnosis related to these efficiency measure of research productivity.

Output Assessment

The variety and range of research outputs is extensive. Such measures could include, patents, new products, recognized technological advances, and personnel trained to carry out research activity. However, all research output, particularly basic higher-education-based research is dependent on the communication of results in the form of publications. Hence, in spite of the many limitations associated with research publications, they are an important and fundamental measure of research output. Research publications themselves are a multidimensional measure incorporating issues of generality, volume, and exposure range (domestic and international). Further, the quantification of these output dimensions are not without their own problems.

In Sweden as in most countries, the measurement and evaluation of the quantity and quality of academic publications for reputational stratification between and within various faculties is virtually nonexistent. For example, it is probable that even within faculties relative ranking is likely to vary depending on the focus and interest of the researcher and whether the purpose of the researcher is to reach workers with similar technical and policy backgrounds of a broad range of researchers in that subject area of the discipline. Across faculties, the sources of variation are going to be even greater. In Sweden, in particular, there may be political and social attitudes related to egalitarian educational objectives that make such rating activity less palatable. This is in contrast to the competitive reputational standing associated with US academia and enforced through economic incentives associated with positive publication performance.

"Bibliometricians" have analyzed the quantitative aspects of publications addressing such issues as: author citation levels, growth rates of the journal of literature, time lapse between reception, acceptance and publication of research, and estimation of production patterns in scientific publications.

Is the number of articles published a sufficient criterion of the author's research performance? The affirmative answers are not completely satisfactory. The "LPU" (Least Publishable Unit) is well known. In order to maximize publishing levels, some authors publish their new contributions by minimum increments in order to maximize publications while others use the "Russian method" of publishing the same article many times by introducing marginal changes. The former is more typical of natural science (eg., chemistry) while the latter is more common in the social sciences (eg., economics). Other authors use the "cross fertilization method," that is, two authors produce a new third article by merging two of their own old articles. Such methods add only marginal improvements to general knowledge. We also have the research manager with unlimited labor resources and sufficient finances to synthesize the work of research assistants. A typical example of the last type is the preparation of Myrdal's great work "Asian Drama" which utilized a fleet of assistants. While there is little doubt the value added by the "manager" made a significant difference between an average and a monumental publication, it generates a difficult measurement problem.

Another measurement puzzle in evaluating a scholar's publications, is whether the lifetime stock or the current flow should be taken into consideration. The evaluation policy in the international versus the domestic journal environment must also be weighted. Further estimation problems associated with multiple authorship is also important.

Bearing these difficulties in mind, some research productivity workers argued that the "quality" instead of "quantity" of the publications must also be emphasized. A quality index may be calculated on the basis of the frequency of references (or citation index) made to a specific author' work. This index at least indicates to what extent other scholars find the work useful and relevant to their own published ideas. Since the pioneer work in citation evaluation by Garfield (1963) and de Sola Price (1965), research evaluation has been concentrated on "qualitative" issues using reasoned judgement. In general, this means giving weight to a series of assessments: (1) who cites whom, (2) citation frequency per author, (3) communication networks, (4) temporal decay of citations, (5) citation frequency per article, (6) the leading scientist's power bias, and (7) cross reference patterns among journals.

However, some cautions concerning the use of citation indices are well justified. As Garfield says: "It is preposterous to conclude blindly that the most quoted author deserves a Noble Prize. On this basis, Lysneko and others might have been judged the greatest scientists of the last decade." In other words, there is no discrimination between favorable and unfavorable citations. Despite Garfield's dictum, Quandt (1976) predicted with a high degree of accuracy the future Nobel Prize recipients in economics from citation frequencies for 1970s.

Another argument against the use of citation indices as a screening mechanism can be outlined for the field of economics as follows: Shall we give more value to Samuelson's elementary book *Economics* than to his other pathbreaking book *Foundations* just because of its higher citation index score? On the other hand, given the fundamental uncertainty of research evaluation, the "law of large numbers" may prove useful. Authors with higher citation frequencies, are most likely eminent scholars with significant influence. In any event, a high citation frequency indicates that a contribution has had a clear influence in the scientific field in question. The appropriate evaluation of research must be in terms of scientific "value added" but as we have indicated this is not an easily quantifiable distillation.

The outputs of the Swedish research process may be classified in the following categories: books, working papers, articles published in Swedish journals, and articles published in international journals. The choice of the last category of article output used in the empirical application of this paper, may be justified by the more rigorous publication screening in highly competitive international journals. The publication of books is considered important. However, they will be ignored here not only to simplify calculations, but also, from a publication supply perspective. Books and articles may be seen as "complementary goods," in the sense that books are often extensions or popularizations of contributions that have already appeared in brief and more technical forms in journals. Further the gestation period of books is significant and may be less responsive in the short term to policy targets related to raising research activity in a given sector. On the demand side, citation indices show that articles are referred to more frequently than books and hence provide a better index of quality for journals.

Output: Building Sector Data Base

The output data used for this study was generated by an online search of Compendex and Bodil. Compendex is the database version of the Engineering Index utilizing the database-host European Space Agency/Information Retrieval Services (ESA/IRS). The Swedish building sector research references used the 1985-87 period and the appropriate two digit standard industrial classification codes. This search yielded 476 references. The quality of articles is ignored, as well as the type of analytic technique. This approach gives us the Swedish publication activity in a specific sector of the whole market for the journals covered by Compendex during the time period.

Bodil is another building sector database, which is operated by a database-host program called Byggdok. It includes reports, books, dissertations, and grey literature published by Swedish institutions in both Swedish and other languages during the same period. The language distribution is Swedish 32%, English 42%, German 15%, other languages 21%. The

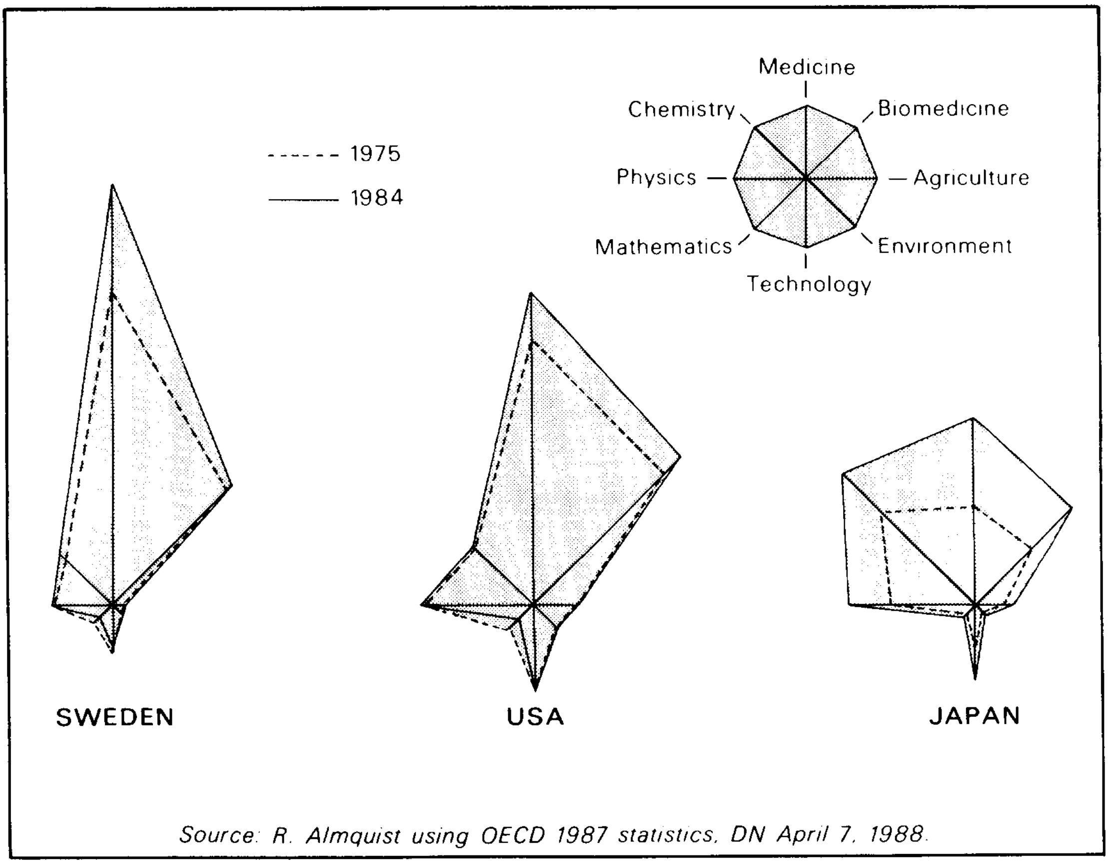

FIGURE 1. Research Profiles of Sweden, USA, and Japan.

databases Bodil and Compendex are complementary to each other.

In order to fully appreciate our database and the following analysis with respect to Sweden, it may be fruitful to compare research profiles of nations, in a corresponding multidimensional fashion. In Figure 1, the research profile of Sweden in comparison to the United States and Japan is illustrated. The weighted center of Swedish research growth lies in clinical medicine, while the share of research in technology is rather small. Technology research constitutes a substantial part of the building sector research.

The International Output Dimension

The average Swedish share of total world building sector research publications is about 0.75%, that is, almost the same share as the total Swedish research publication output in the Compendex (0.73%). It is lower that the average national share of global research publications

TABLE 1. The Swedish Share of Total World's Building Sector Publications by Subject

Percent	
Civil Engineering	
Bridges and Tunnels	.5
Buildings and Towers	.9
Urban and Regional Planning	1.1
Military Engineering	.8
Construction Equipment	.6
Highway Equipment	.6
Maritime and Port Structures	.5
Structural Design	.7
Construction Materials	
Bituminous Materials	.7
Concrete	.9
Insulating Materials	1.0
Masony Materials	.7
Metals, Plastics, and Wood Materials	.6
Materials Properties and Testing	
Strength of Materials	.7
Test Equipment and Methods	.7
Miscellaneous Properties and Tests of Materials	.9

Source: Inforsk using Online-search in Compendex via ESA/IRS

1.7% (Inforsk, Bibliometriska Notiser No. 2, 1988).

In Table 1, the Swedish publication of articles in building research is given by subject as a percentage of world publication output. The highest publication rate is observed in Urban and Regional Planning with 1.1%, and the lowest rate is in the subject areas of Bridges and Tunnels and Maritime and Port Structures with 0.5% each.

Domestic Output Considerations

This study is conducted at an aggregate level. In Table 2, we describe the building research publication output (473 articles) in Sweden by region and organization during the 1985-1987 period using Compendex as previously outlined.

From Table 2, it is clear that the Stockholm region is the dominant region producing 40% of the total publication activity in Sweden. Stockholm and Gothenburg regions published almost 60% of the research output publication of the Swedish academe in this subject area.

In the subsequent analysis, we shall focus only on the first six elements of the first column of Table 2, which is the regional distribution of publications made by "higher education institutes."

University and Technological Institute outputs are aggregated in a following pattern:

1. Stockholm: Stockholm University, Royal Inst. of Technology
2. Gothenburg: Gothenburg University, Chalmer Inst. of Technology
3. Lund: Lund University
4. Uppsala: Uppsala University
5. Linkoping: Linkoping University
6. North: Umea University, Lulea Institute of Technology

Table 3 indicates the spatial distribution of publications for the more productive organizations with at least 4 research journal publications. The information in the Table 3 suggests that the institutes with the high publication production are the Institute of Lightweight Structures in Stockholm

TABLE 2. The Publication Output in Sweden by Region and Organization

Region	Higher Education	Industry	Research
Stockholm	85	30	74
Gothenburg	77	8	3
Lund	36	0	1
Uppsala	22	0	1
Linkoping	14	1	4
North	36	0	2
Vasteras	0	15	0
Borlange	0	4	1
Hoganas	0	3	0
Gavle	0	0	3
Malmo	0	3	0
Total	270	64	89

Source: Compendex

with 17 articles, the Institute of Physics in Gothenburg, and the Institute of Strength of Materials in the north region. On a national scale the Institute Strength of Materials exhibits the highest publication averages.

Nonjournal Output

The next step is to enlarge the publication sample, by including books, working papers, and a citation index as a "quality output."

The Bodil database generated 5166 references to building sector publications in Sweden for the period 1985-87, of which 4,131 references can be distributed across regions as illustrated in Table 4.

Table 4 also suggests that the Stockholm region is the dominant region producing 60% of all publication units in Sweden. Further the Stockholm and Gothenburg regions are responsible for 65% of the Swedish academy. However, the publication output of nonacademic research centers (e.g., research institutes, industries) is greater than the output of the academic research centers.

Output Quality

TABLE 3. Building Sector Publications by Region and Type of Organization

Organization	Stock	Gothen	Lund	Uppsala	Linkop	North
Light-weight Structures	17					
Work Science/Polymer	6					
Strength of Materials	5	9	5		4	13
Physics		13				
Structural Mechanics		4				
Mater Science				7		
Inorg Chemistry				5		
Polymer Tech	4	4				
Physical Metallurgy	4					
Metallurgy/Mater Tech						7

TABLE 4. The Publication Output by Region and Organization

Region	No.	Output from institutes of higher education	Total
Stockholm	1	301	3159
Gothenburg	2	345	441
Lund	3	184	216
Uppsala	4	61	74
Linkoping	5	5	158
North	6	68	83

Source: Bodil database

The quality of the published output may be measured by a citation index from the Science Citation Index (SCI) database, which incorporates the world's most important scientific and technical journals. It is interesting to note that only a small number (6%) of the current body of more than 100,000 scientific and technical journals is found to be predominant in the citation network.

The output quality aggregate index is the sum of all citations for the Compendex-publications for each higher education region. For this study, the use of a direct citation index was not fruitful. The main explanation for this may be that the citation maturity period lies between 5 to 10 years after the publication date. Hence, the selected period of 1985-87 for our databases does not allow for this type of "citation maturity." Thus, the use of an indirect citation index such as impact factor index may be considered appropriate. Instead of measuring the "actual" citation of each article we measure its journal's "potential" by using the "prestige" of each journal in which an article has been published. According to Garfield, the impact factor is a measure of the frequency with which the "average article" in a journal has been cited in a particular year. In other words, the impact factor is basically a ratio between citations and citable items published. Figure 2 illustrates the regional distribution of the aggregate index of output quality.

Although this indirect citation index does not fully measure the nonscientific advantages of large, older, frequently issued journals, (e.g., availability and extent of library holdings, coverage by secondary services, etc.) it does allow some evaluation of quantitative data.

In summary, our output measures of building sector research productivity focus on research publications. These are measured for the period 1985-1987 and are evaluated quantitatively through two major online data bases for formal journal output levels and nonjournal "grey literature" outputs. Further an index of output quality is also constructed and incorporated into the assessment. Finally, these results by authors and institutions are aggregated to six major regions in Sweden.

INPUT ASSESSMENT

Outputs only occur because inputs are put into productive use. In this section we review the inputs to the creation of building sector research in Sweden.

Labor Inputs

In this study, two different sources of labor inputs will be used. The first type of data is derived from the Sweden Statistics' "Background Material for Institutes of Higher Education" (1987, p.4), which gives total manpower of each research organization expressed in man-years.

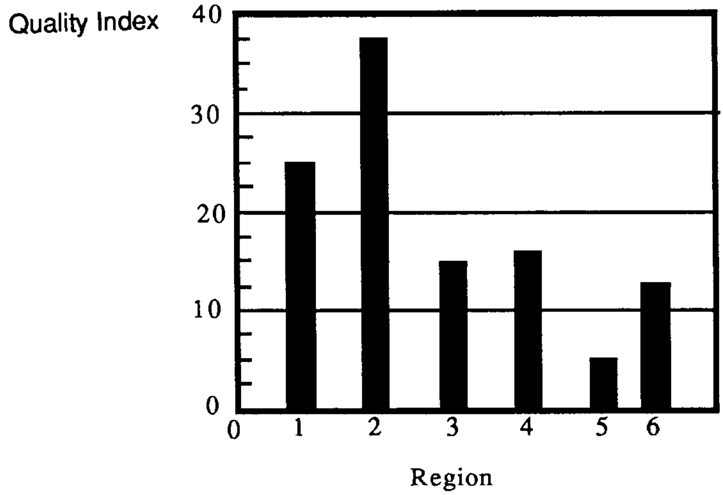

FIGURE 2. Output Quality Aggregate Index.

The quality of these statistics is very poor, because of the lack of common classification systems for personnel among institutions in various regions.

The second type of data for labor inputs is collected by taking the personnel register of each author's institute. The major benefit of this microlevel data collection is that, it better reflects the creative milieu of each author. However, this data, using a register, has a major limitation. It does not specify man-year data or fully disaggregate the full-time/part-time distinction necessary for the traditional econometric estimation of production functions.

The number of scientists rather than full-time equivalent as a measure of input does not resolve the conflict between the number of heads versus the number of man-hours that determines the effectiveness of research. This is the consequence of the lack of a detailed statistical base. The major weakness of the personnel register is that it introduces as upward bias in the labor inputs.

The labor inputs are the academic staff classified into three categories: professors, researchers, and assistants. The first category is relatively homogeneous, but the other categories are very heterogeneous, especially among universities and across institutes of technology. In the second category, the following positions are included: docent, lector, research fellow, and research engineer. The third category includes research assistants and engineers. Students working toward their PhD but not employed by the institute are not included. These categories represent the labor resources which institutes utilize most in the research process. The number of technicians was not taken into account because they do not play any independent role in the research process.

Professors have a secondary research production level in comparison with the other labor input categories. The majority of articles is produced by the researcher category. These are individuals with full-time commitment to research while professors and assistants have teaching, organization, and maintenance commitments as well as research. Another possible explanation is that professors in these building industry oriented disciplines have higher alternative costs than professors from many other disciplines. They may be occupied with other activities such as private sector-oriented research and consultancy.

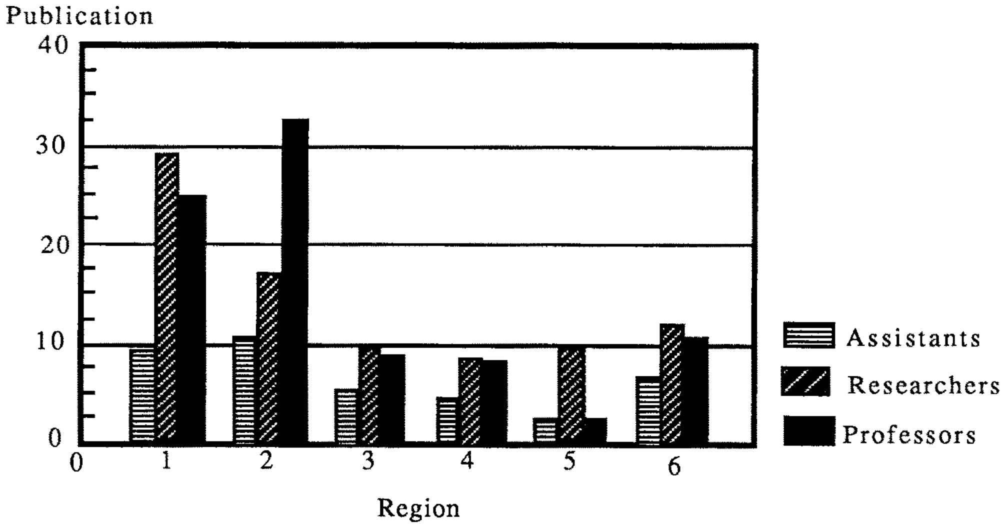

FIGURE 3. Number of Publications by Region and by Researcher Category.

Other significant results may emerge when factors that could influence labor performance in a research organization are included, for example, R & D experience of the members or characteristics of R&D leaders.

Given the lag between input activity and output results, if the publication period is 1985-1987 the base year for labor input should be about 1984.

Figure 3 exhibits the spatial profile of publication by input category, that is, professors, researchers, and assistants. In the case of multiple authorship, we register only the first author. The first author may not be considered as the most important, because often the authors names are ordered alphabetically. By ignoring the other authors, a downward estimation bias is created not only for the other authors, but for another institute in the same region, or even for an institute of other regions depending on the location of authors in a multiple authored work.

Expenditure Inputs

Total expenditures for research in the building sector by institutions is aggregated to regions. Expenditure patterns are largest for the Stockholm and Gothenburg regions as expected and smallest for Linkoping with a higher than expected expenditure in the northern region.

These expenditures include personnel and in that respect double counting occurs. However, they also include equipment, facilities, and logistical costs which are likely to be highest in the urban and northern regions. Although these factors do not offset the regional allocative differences they do reduce them to some extent.

Input-Output Assessment

Efficiency in research and efficiency of research organizations is not less important than efficiency in other production activities. A major policy implication of this study is the possibility of increasing research output without significantly increasing inputs. Two types of efficiency have been employed in the economic literature: economic efficiency requires a correct input (cost minimizing) distribution (allocation) at given input prices, while technical efficiency

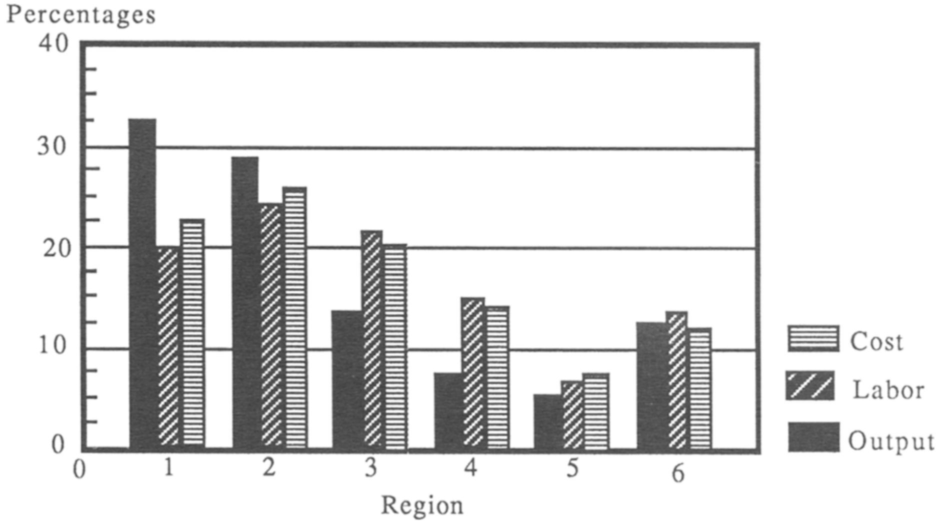

FIGURE. 4. Regional Distribution of Publication Output and Input.

refers to maximizing output for a given set of inputs.

A rather interesting question for the Swedish academe is which region has the higher research publication output in relation to inputs in the context of the building sector studies. It has been argued that the intellectual synergy or performance of research organizations is related to their size. One hypothesis claims that the efficiency actually increases with size (economies of scale). The optimum size hypothesis argues that efficiency increases with the size up to a certain point, after which it decreases. The critical size hypothesis claims that there is an improvement in efficiency when the organization reaches a critical threshold size. These are classic production considerations.

Figure 4 throws some light on this question. It illustrates the aggregate regional distribution of publication output and inputs (labor and total cost) of the institutes of higher learning. Only in two regions, Stockholm and Gothenburg, are the regional shares of outputs bigger than the regional shares of inputs. For the Stockholm region an explanation might be the external economies of research institutes and industries located in the same region. For the Gothenburg regions, the economies of scale of the institutes of higher learning might be an appropriate consideration. The other regions of Lund, Uppsala, and Linkoping show a divergence between the equality of input-output shares. But, it is not possible to draw any definite conclusions about the economies of scale and/or optimally, by using relative shares in an input/output assessment.

To explain the efficiency evaluation of various institutes in a more pedagogical way, let us consider Table 5. In this table, organization A dominates in efficiency over B (by producing the same outputs with less inputs), and organization B in turn dominates over C. But, it is not clear *prima facie* that organization D is more or less efficient than the other research institutes.

To generalize, suppose that *N* institutes research performance must be evaluated. Each insti-

TABLE 5. Efficiency Dominance

Organization	Labor Inputs			Publication Outputs		
	Prof	Resear	Assist	Articles	Stencils	Books
A	3	5	10	1	1	1
B	3	6	12	1	1	1
C	8	10	15	1	1	1

tute is characterized by an input vector **xj** = (x1j, x2**j**, x3**j**), which indicates the distribution of input within the time period: professors, researcher, and assistants. Each institute has also an output vector **yj**, which shows the number of published articles in international journals, stencils, and books, **yj** = (y1**j**, y2**j**, y3**j**). Thus, a research production function of an institute **j** for **j** = 1, 2, 2 . . . , *N*, may be written in a vector form **yj** = **F**(**xj**).

EFFICIENCY EVALUATION

Farrell's Efficiency

Tracing back 30 years, we begin with the seminal work of Farrell (1957) in the measurement of a firm's efficiency, inspired from the works of Debreu (1951) and Koopmans (1951). Economists have extended the methodology for estimating measures of efficiency since that time. Forsund et al. (1980), and Forsund and Hjalmarsson (1987) have composed concise introductions to this area, both in a deterministic and stochastic framework.

Farrell's work is rooted in maximizing behavior. It may be summarized in the following way: assume constant returns to scale, $y = F(x1, x2)$, so that the frontier technology can be characterized by a unit isoquant. The isoquant can be derived from the production function, by transforming the factor space into the space of input coefficients. This unit isoquant is illustrated by Figure 5.

Let point *A* in Figure 5 represent a given input mix $(x1, x2)$ and connect point *A* with the origin *O* by the line *OA*, intersecting the isoquant at *B*. The ratio *OB*/*OA* measures technical efficiency. It is the ratio between inputs needed to produce a given output, and the inputs actually used to produce this output, given the input-mix used. Farrell's method has been generalized by, among others, Fare (1978), to deal with nonconstant returns to scale but still assuming a single (simple) production function. The measure is not dependent on any functional form of the frontier, ie. it is a nonparametric approach. The basic limitation is that the linearity assumption is restrictive and the generalization is complex. Another limitation of the approach is that the frontier is very sensitive to extreme observations and measurement error.

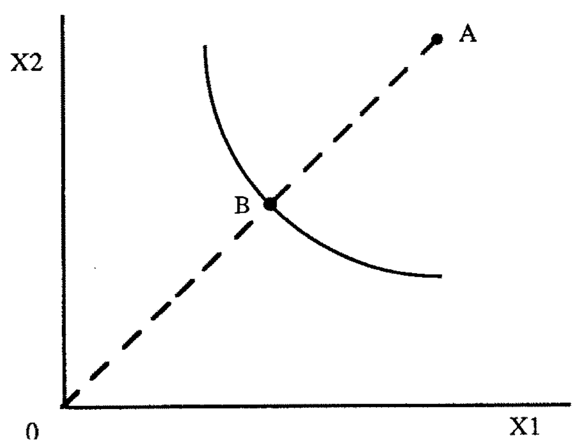

FIGURE 5. Farrell's Efficiency Measure.

Production Function

A production process is usually modelled by means of a production function. Estimation of a production function provides another method that has been used to measure efficiency. The production function is a specific input-output relationship, which represents the maximum achievable output for each given vector, that is, it is an extremal relation. The degree to which the actual output of a production unit approaches its maximum level depends on its technical efficiency. It is defined by a reference to a given state of managerial and engineering knowledge.

In practice, production functions have been formulated in either a deterministic or stochastic form. Deterministic production functions are usually estimated with one-sided errors, while stochastic frontiers are estimated with two-sided errors. In a deterministic function it is assumed that all inputs and external factors influence the production process with a maximum bounded effect. This assumption ensures that all output observations are below the frontier.

The following deterministic parametric approach of efficiency estimation proposed by Farrell and modified by his adherents Aignier and Chu (1968) is applied by taking the logarithm of a Cobb-Douglas production frontier $y = F(x) \exp(-u)$, we get $\ln y - \ln F(x) - u$, for $u <= 0$ where the error term u (representing technical inefficiency) implies $y <= F(x)$. The coefficients of the Cobb-Douglas function can be estimated either, by the maximum likelihood estimation (MLE), on more frequently by the corrected ordinary least squares (COLS) of OLS assuming that u and x are independently distributed.

The basic advantages of this approach are the simplicity of the mathematical expression of the production frontier and the accommodation of a nonconstant return to scale process. On the other hand, the rationale of using stochastic frontiers is that a production unit's efficiency may be influenced by factors outside its control,for example, weather conditions. A stochastic production frontier may be modelled by $y = F(x) \exp(x-u)$ assuming that x and u are independent. The coefficients of the stochastic frontier can be estimated by either MLE or COLS methods. An important distinction may be pointed out, concerning the stochastic production frontier. The frontier is called an average function, because it is related not to the maximum output (as in the deterministic frontier), but to the mean output, given the set of inputs.

The most common type of application has remained the case with a single output. In situations with more than one output, the following two methods have been used. A regression is repeated for each output; thereby ignoring the simultaneity of the production process or the multiple outputs are transformed to a compound measure via an arbitrary weighting scheme, for example, one book is approximated by three articles. A better method of treating the multi-output efficiency is to estimate the structural equations simultaneously; it is still possible to estimate the reduced form equations for each output using OLS.

In the case of a stochastic frontier, while some inputs of external factors have unbounded effects, the maximum possible output is random, that is, some output observation can be above the frontier. The basic disadvantages of this efficiency evaluation method using production functions are major. Production function estimations do not define the most efficient way of using a given input vector. The existence of multicolinearity of inputs may give the wrong estimations of the coefficients. Further, there is no a priori information for specifying the parametric functional form of a production process. Finally, the meaning of "technical efficiency" is not well defined and accepted by a large group of economists. Levin's (1974) pessimistic overview indicates:

> The implications of estimates of public sector production functions for improving social efficiency should probably be stated with far greater modesty than they have been. They may be totally misleading.

Data Envelopment Analysis

A mathematical programming model applied to input-output data gives estimates of extremal input-output relations like the procedures applied to observational data which are used to establish an efficiency frontier via an envelope function of all production processes. This is called Data Envelopment Analysis first pioneered Charnes, Cooper, and Rhodes (1978). In this characterization an organization is considered to be efficient, if and only if, there does not exist a linear combination of institutions which dominate a given organization. Consequently, the mathematical programming problem is to find the most dominant linear-combination if such exists. If the resulting indexes for a given organization has an efficiency ratio of one, then the organization is said to be efficient and is on the efficiency envelope frontier. If the efficiency ratio is less than one, then that organization is said to be inefficient relative to the organization that dominates it. This is done through a linear programming (LP) assessment of each organization of decision making units (DMU).

By applying the LP model N times — once for each organization (DHU) — we get the efficiency index of each organization. There are many computer programs to solve the N linear programming models via a modified simplex method. A good description of these statistical packages may be found in Sharda (1984).

The basic advantages of DEA are that it provides all the information of production function estimation but it does not require the production function to be specified in parametric form a priori and the resulting scalar of efficiency is obtained from LP methods, in which all inputs and outputs are explicit.

DEA EFFICIENCY RESULTS

The purpose of this study was to apply a framework for the analysis of building sector research publication efficiency applicable to the six regions of higher education in Sweden. By applying the DEA to input-output data in Sweden, we get the efficiency ratings illustrated in Figure 6. These ratings, with respect to the building sector research differentiated by region indicate that the more efficient regions of higher education research are the institutions of the urban and coastal regions of Stockholm, Gothenburg, and the newer institutions of the northern region. The "troubled" regions are the interior universities including the oldest universities of Lund and Uppsala and the new university of Linkoping. To explain the *raison d'etre* of this regional research differentiation goes beyond the scope of this paper. To identify the causes of efficiency divergence, one should look at the organizational "climate," research-teaching balance, and so forth. Further, there is diagnostic evidence in DEA results which can be explored.

CONCLUSIONS

By linking the data-base host Compendex to the database EAS/IRS, it is possible to classify global article production according to geographical location, subject, and type of research organization during a specific time period. Although the treatment of research efficiency has been quite superficial up to now in Sweden, the message of this study should be clear and illustrative. There is a differentiation between the various regions of higher learning in relation to building research productivity publication in Sweden. This evaluation does not reflect an appraisal of institutional integrity, but it should encourage flexibility, so that adjustments can be made. The method is beneficial because it allows one to distinguish between "active" institute regions and "trouble" institute regions in the R&D process. The policy relevance of DEA is that it identifies where the efforts for efficiency improvement should be concentrated. By estimating the research efficiency of higher institutes of learning it becomes easier to under-

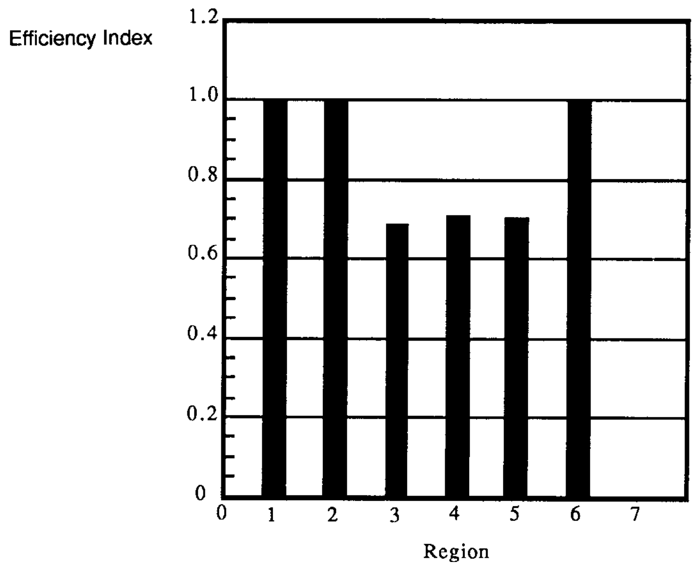

FIGURE 6. Efficiency Ratings.

stand total efficiency of other nonprofit knowledge intensive institutions.

It would be speculative to suggest that the evaluation of an organization could be entirely based on a DEA application. It is clear that DEA has some drawbacks as a method for research evaluation. Grosskopf (1986) has argued that the absence of a more general reference technology in DEA creates a downward bias of the calculated efficiency values. Thus, DEA has been demonstrated as a screening device for accountability of research productivity if it is combined with other quantitative and qualitative criteria.

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