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Abstract: This study estimates for the first time translog cost functions for 147 American doctorate granting universities, accounting for three major products of these institutions: undergraduate and graduate instruction and research. New measures of research output and quality are employed that do not merely use research expenditures as the output proxy. Evidence is found for strong economies of scale for the average institution, as well as economies of scope related to the joint production of undergraduate and graduate instruction. The public or private ownership of an institution is shown to be insignificant for most cost components considered. Only institutional support costs are significantly higher in the private sector. Part of the difference, however, can be attributed to major fundraising costs in the private sector. The intensity of state regulation of personnel and administrative practices in the public sector does not appear to have a significant impact on production efficiency.

I Introduction

For a long time research on the economics of higher education has recognized the possible effects of the scale of operations for the efficiency of higher education (see Brinkman and Leslie, 1986 for an overview of different studies). The collection of empirical evidence has been slow, however, in particular for research universities. The complicated, multiple-product character of these institutions makes analysis difficult. At the same time, scholars have expressed concerns for the possible inefficiencies introduced in the public sector by the intensity of government regulation of the production process, adding another complicating factor to the analysis. For an overview of the issue of campus autonomy and state regulation, see Volkwein (1987, 1989).

Techniques to analyze multi-product firms have been available for some time, originating from the work of Baumol et al (1982) and have been applied to a wide range of industries, such as telecommunications, rail roads and hospitals (for references, see Wang and Friedlaender, 1985) and most recently by Cohn et al (1989) to higher education.

Cohn et al (1989) for the first time have analyzed higher education in the U.S.A. utilizing multi-product cost concepts. They studied economies of scale and scope for a large sample of 1887 institutions of higher education, essentially covering all four year institutions. The objective of this paper is to extend their research in four ways and to provide an independent verification of some of their results. First, by focusing on a subsample of 147 doctorate granting universities we are able to draw specific conclusions on this important group of institutions with a large research emphasis. Second, we study the sensitivity of cost function estimates to different output measures. In particular, we employ explicit measures for research output, such as the number of publications, instead of the dollar value of research grants used by Cohn et al. This allows us to account for research productivity differences between institutions. The sensitivity of the results to the inclusion of a (graduate) program quality measure is also studied. Third, our use of the translog cost function allows for some interesting comparisons with the quadratic cost function employed by Cohn et al. Fourth, the impact of state regulation of personnel and government practices on production efficiency in public higher education is investigated using an explicit measure of the degree of state regulation. This allows us to address the issue of state regulation and productive efficiency empirically, while acounting for other determinants of the cost structure through the cost function approach.

In section II we formulate the theoretical framework for this study, while section III describes the data employed. In section IV the results of the estimated cost functions for research universities are reported and compared with other studies. Section V adds a sensitivity analysis to explore the dependence of the results to different output proxies, including peer ratings of program quality. In section VI we focus on the possible effects of state regulation for institutional efficiency. Finally, the conclusions are summarized in section VII.

II Theoretical Framework

An adequate empirical test of different hypotheses regarding the influences of economies of scale and scope and of government regulation requires a theoretical basis that explains the behaviour of a non-profit organizations such as an universities. Several attempts to formulate a theory of the behaviour of the non-profit university have been made. The university as a prestige-maximizing entity has been put forward by Garvin (1980). Other theories model the university as a labor cooperative (James and Neuberger, 1986). More general theories of non-profit organizations give a heavy emphasis to some form of output maximization as the basis of non-profit behaviour (James and Rose-Ackerman, 1986). Outputs such as the quantity and quality of instruction, research and public service, are possible candidates for output measures. Other theories include often unobservable outputs, such as bureaucratic perks and prestige. Neither of these theories is supported by robust empirical evidence.

Our approach in this study will be rather pragmatic. There seems to be consensus on the primary objectives of a research university organization: producing instruction and research[1]. We assume that some form of cost minimization plays a role in decision making at all levels. Once budgets are fixed at a particular level in an organization, both administrators and faculty try to maximize outputs given these restrictions, which is equivalent to minimizing costs per unit of output. Of course, the precise relative weights of different outputs are not made explicit. For our purpose it is sufficient to assume that these relative weights do not differ very much among research universities. This implies that production costs, essentially the costs of such inputs as labour, equipment and capital, are a well-behaved function of output quantities and input prices. Given the competitive, national labor market for faculty and senior administators at research universities, it may be assumed that salaries and wages are similar within each discipline at different institutions for those with comparable (research) productivity. This implies that we can omit differences in labor input prices in our estimates of cost functions for research universities. Although the same assumption for the prices of equipment and capital is more difficult to justify, we have omitted those prices too, given the large share of labor costs in total costs, and, therefore, the relatively small sensitivity of those costs to non-labor prices.

A general translog cost function has been employed to model the cost structure of our sample of research universities. This function has been widely used to study multi-product industries such as telecommunications, hospitals, trucking and railroads (for references, see Wang and Friedlaender, 1985). The translog cost function has the advantage of a flexible specification, allowing for both economies of scale and economies of scope. The latter imply cost savings when producing more than one output within the same firm or organization. Moreover, these economies of scale and scope are not necessarily of the same magnitude across the entire output range, allowing for a realistic description of costs. Unlike the fixed cost quadratic function, employed by Cohn et al (1989), the translog does not allow for a zero level of one or more of the outputs. However, in our subsample of non-specialized doctorate granting universities all institutions have non-zero values for the outputs considered.

In this study three outputs will be employed: undergraduate instruction, graduate instruction and research, to be proxied in different ways. The cost function can be expressed as follows:

$$\log C(q1,q2,q3) = k + \Sigma_i \, a_i \log(q_i) + \Sigma_{i \leq j} \, a_{ij} \log(q_i) \log(q_j) \tag{1}$$

in which:

C = total costs

q1 = undergraduate instruction output

q2 = graduate instruction output

q3 = research output

k = constant

ai, aij = coefficients

In addition to the independent variables included in equation

(1), different dummy-variables are used to account for the type of control of an institution (public or private[2]), different degrees of regulation within the public sector and the existence of a medical school, which is an important determinant of the internal cost structure.

In the actual estimates all variables will be scaled to 1 at their respective means. This facilitates the interpretation of the regression coefficients. For instance, the coefficients of the terms log linear in output represent elasticities of each output at its sample mean. Local (ray) economies of scale are conveniently measured by the scale elasticity (SC) or ray economies of scale coefficient (Jorgenson, 1986) defined as:

$$SC = 1 / \Sigma_i [\delta \ln (C) / \delta \ln (q_i)] \quad (2)$$

The scale elasticity measures the percent expansion of the outputs (all at the same rate, i.e. along a ray in output space), which can be obtained by a one percent increase of costs. If the scale elasticity is larger (smaller) than 1, the producer is locally operating under ray economies (diseconomies) of scale. Minimum ray average costs are obtained at a scale elasticity of 1.

To facilitate the interpretation of the cost structure estimated, we will calculate average costs along expansion paths in in three dimensional output space. A useful path is that along a ray through the origin in output space, <u>keeping output proportions</u>

fixed. Along this line segment ray average costs can be defined, a widely used concept in studies of multi-product firms (see Baumol et al, 1982). Essentially it measures the cost of a bundle of outputs, defined as a multiple of a given output vector, relative to the costs of this 'unit bundle'. It is formally defined as follows:

$$RAC = C(\mu q1, \mu q2, \mu q3) / \mu \qquad (3)$$

in which:

RAC = ray average costs

μ = number of units in the bundle $q = (\mu q_1, \mu q_2, \mu q_3)$

q1 = undergraduate enrollment for the unit bundle

q2 = graduate enrollment for the unit bundle

q3 = number of publications for the unit bundle

Given a well-behaved cost function, minimum ray average costs are usually achieved somewhere along the ray. Note, however, that for each ray in output space, corresponding with different output proportions in the unit bundle, such a minimum generally can be found. The set of minima is designated the M-locus and plays an important role in the analysis of the optimal industry structure.

Although ray average costs is a useful concept, other expansion paths in output space are feasible, not necessarily along a ray with fixed output proportions. In the case of research universities for instance, the actual history of most institutions shows an expansion path typically not along a ray. For instance, a typical small college provides only undergraduate education. University status will often be obtained at a larger size, as graduate education and research also are produced. The typical private university then limits undergraduate enrollment to fairly small values, while the typical public university would continue to expand undergraduate enrollment. Finally, also in the latter case undergraduate enrollment levels off, with the other outputs possibly still increasing. This calls for exploration of other directions in output space, using variable output proportions. Important directions are those in which one of the outputs is variable while the others remain at given values. The total costs per unit of the variable output - including the costs of producing the other two outputs at given levels - can be calculated along the line segment parallel to the variable output axis. We will refer to them as 'variable proportions average costs' (VAC) defined as[3]:

$$VAC_i = C\ (\ q_i,\ q_{j0},\ q_{k0}\ )\ /\ q_i \qquad (4)$$

in which:

VAC_i = variable proportions average costs per unit of output i

q_i = level of output i

q_{j0} = level of output j

q_{k0} = level of output k

Another useful multi-product cost concept is that of economies of scope. Economies of scope refer to cost savings that are obtained when producing one product together with another product, instead of having firms specializing in each of the products. A sufficient condition for economies of scope is (Baumol et al, 1982) :

$$\delta C / \delta q_i \delta q_j < 0 \qquad \text{for all pairs } i,j \tag{7}$$

For the translog cost function this condition can be easily calculated and reduces to the following condition at the sample mean[4]:

$$a_{ij} + a_i a_j < 0 \tag{8}$$

This condition can be conveniently tested for statistical significance with a standard Wald test.

Cost functions will estimated for total costs, for the costs of the primary process of producing instruction and research and for the costs of different types of supportive services, such as academic support, student services, institutional support and operation and maintance of plant. In this study, total costs are defined as education and general expenditures according to the definitions of the national HEGIS-survey (see section III), minus expenditures on public service and income transfers such as student scholarships. Public service is excluded since we lack any data on corresponding output. Income transfers do not directly affect production costs and are omitted for that reason.

Lack of comparable data excludes a more accurate definition of costs. Although data are available on capital costs, we have excluded them from the present analysis. They are calculated very differently from institution to institution, depending on depreciation rules and other conventions regarding the treatment of capital assets. Our cost functions therefore essentially represent variable costs. We will define primary costs or expenditures as the sum of expenditures on instruction and research as defined in the HEGIS-surveys. An interesting advantage of this cost function approach is that it does not require the sometimes very arbitrary allocation of costs to separate functions, such as instruction and research. Moreover, the possible joint production of instruction and research - as allowed for by the translog cost function - would exclude the a priori allocation of inputs to different outputs.

In the case of supportive services, direct output indicators- such as the number of pay checks issued, the number of library books circulated - are not available. In those cases we will simply estimate the relationship between costs of supportive services and the primary outputs, the two types of instruction and - if relevant - research. The resulting statistical cost functions cannot be interpreted as cost functions in the traditional sense, but they reveal some information on the amount of supportive inputs used to produce a particular bundle of primary outputs.

The definition of the primary output quantities constitutes an important problem. A measure of the final output of the instruction and research process, such as the added knowledge and skills of students and the effects of research in enlarging knowledge and improving technology, is very difficult to measure. Most cost studies proxy outputs with simple, intermediate output indicators such as the number of students or degrees. Most studies approximate research output by research expenditure, which obviously defines away differences in productivity (see Leslie and Brinkman, 1986). Quality aspects are usually neglected when using simple quantity measures.

We use three output measures in our main analysis. Teaching or educational output is measured by full-time-equivalent undergraduate enrollment and full-time equivalent graduate enrollment. A sensitivity analysis is performed by replacing these proxies by the number of earned undergraduate and graduate degrees respectively. For research output we employ a quantitative output measure, the number of research publications, improving on often employed input measures, such as research expenditures. Our standard proxy will be Also, as a part of our sensitivity analysis we include peer ratings of gradate program quality as an additional output variable. This allows us to study the possible significance of neglected quality differences in the main analysis. Details on the employed proxies will be given in section III.

In this study, which focuses on the institutional level, we have not disaggregated instruction or research output by field. The relatively broad range of undergraduate and graduate programs offered by most universities in our sample does not warrant disaggregation at this stage. To create a sample as homogeneous as possible with respect to the internal output mix, we have restricted our sample to non-specialized, doctorate granting institutions conform the Carnegie classification of higher education institutions (Carnegie, 1987).

III Data

To obtain a useful set of combined cost, output and regulation data we matched various data files from different sources. The cost data were essentially expenditure data, collected by the National Center of Educational Statistics, the so-called HEGIS (Higher Education General Information Survey) files. Enrollment and earned degrees data were also obtained from HEGIS-files.

Research output was obtained using the data of the study of the Council of Associated Research Councils (Jones et al, 1982). This study is a very extensive survey of research-doctorate programs, covering more than 200 institutions and 32 fields. This database seems to be the most comprehensive survey of research output available for the early eighties. We utilized the data of the survey on the number of publications and the peer ratings of the programs considered[5]. Finally, data on the regulation of public universities, were obtained from the 1983 Volkwein survey of 86 public research universities (see Volkwein, 1987). The absence of recent, systematic data on state regulation practices and research output, which are not collected nationwide on a regular basis, forces us to use the fiscal year 1982-1983 as the basic year for the empirical test. Given our objective of discovering structural relations, this does not present a serious disadvantage.

The sample has been constructed by taking the Conference Board sample, matching this with the different HEGIS files and selecting all non-specialized, doctorate granting institutions according to the Carnegie classification. Expenditure data pertain to the fiscal year 1983 (ending September 30 1983). Enrollment data are for the fall of 1982, earned degrees are obtained for the academic year 1982-1983. Publications are measured over the 1978-1979 period.

IV Empirical Results

In this section we present the econometric estimates of different translog output cost functions for our sample of 147 doctorate granting institutions and explore their implications. Table 1 contains the OLS-regression results for the total costs, the primary production costs and four components of supportive costs as a function of the three outputs, a dummy variable for private/public ownership and a dummy variable for the presence of a medical school. The four components are: academic support, student services, institutional support and operation and maintenance of plant. All variables are scaled to 1 at their sample means to facilitate the interpretation of the regression coefficients.

(table 1 here)

- For all cost components the coefficients of the terms linear in the log of output are all significantly different from zero, except in the case of academic support costs. The values of the scale elasticities, evaluated at the sample mean, are larger than 1, indicating economies of scale at the mean output vector. Economies of scale are most pronounced for academic support and student services, and smallest for operation and maintenance of plant.

- The coefficients of the terms quadratic in (log) output in ther estimates for total and primary costs are significantly different from zero for publications and graduate enrollment, but not for undergraduate enrollment. This indicates that, although economies of scale are present when expanding each of the outputs at the sample mean, costs per output unit - keeping other outputs constant - eventually will increase with continued expansion of graduate enrollment or research output.

- The interaction term between undergraduate and graduate enrollment in the cost function is clearly significantly different from zero, while the interaction between graduate enrollment and publications is very close to the 5% significance level. A Wald test shows that the vector $a_i a_j + a_{ij}$ is significantly different from

Table 1 Estimation results for six categories of costs

cost category coefficient	total costs	primary costs	academic support	student services	institutional support	operation maintenan plant
constant	-0.15* (3.8)	-0.17* (3.6)	-0.079 (1.0)	-0.26* (2.9)	-0.20* (2.8)	-0.11* (2.2)
a1	0.21* (3.6)	0.19* (2.8)	-0.068 (0.65)	0.42* (3.2)	0.33* (3.1)	0.29* (3.9)
a2	0.25* (4.3)	0.22* (3.2)	0.39* (3.7)	0.32* (3.0)	0.24* (2.3)	0.31* (4.2)
a3	0.34* (10.9)	0.40* (10.9)	0.29* (5.1)	-	0.22* (3.8)	0.29* (7.2)
a11	0.051 (1.5)	0.067 (1.6)	-0.22* (3.5)	0.055 (0.69)	0.047 (0.74)	0.091* (2.0)
a22	0.24* (3.6)	0.24* (3.1)	-0.011 (0.096)	0.22* (2.1)	0.29* (2.5)	0.35* (4.1)
a33	0.056* (4.5)	0.060* (4.2)	0.0007 (0.03)	-	0.063* (2.8)	0.058* (3.6)
a12	-0.21* (3.0)	-0.26* (3.3)	0.0049 (0.04)	-0.13 (0.90)	-0.089 (0.72)	-0.23* (2.6)
a13	-0.018 (0.72)	-0.024 (0.83)	0.050 (1.11)	-	-0.0001 (0.002)	0.0013 (0.042)
a23	-0.085 (1.95)	-0.084 (1.66)	0.13 (1.66)	-	-0.21* (2.7)	-0.17* (3.1)
dummy medical school	0.24* (5.6)	0.28* (5.7)	0.28* (3.6)	0.16 (1.6)	0.044 (0.58)	0.094 (1.7)
dummy private control	0.054 (0.92)	-0.002 (0.03)	-0.010 (0.94)	0.13 (0.96)	0.37* (3.5)	0.060 (0.79)
R^2	0.90	0.88	0.72	0.41	0.61	0.83
scale elasticity	1.25	1.23	1.63	1.35	1.27	1.12

(absolute t-statistics in parentheses)
* = significant with p=0.05

zero at the 5% level, implying economies of scope. An interpretation of this finding could be the major cost savings obtained by employing graduate students as teaching assistants at a relatively low price. The interaction term between graduate enrollment and research (significant at the 10% level) could signal the often assumed, but seldom empirically proved, joint production of graduate teaching and research. This would produce cost savings since faculty time can be used jointly to instruct graduate students in research methods and produce research output.

- The dummy variable to control for the existence of a medical school is significant and postive for total and primary costs and academic support, implying a more expensive cost structure for the core of the production process when a medical school is present.
- The type of ownership, public or private, does not significantly influence any of the cost components, with the exception of institutional support. As can be derived from the regression equation, institutional support is about 45% more expensive in the private sector, given the same outputs. At this point, we note that raising of private funds is a much more important, and therefore costly, activity in the private sector as in the public sector. This supposedly explains at least part of the difference. No systematic information is available on fundraising costs, but estimates for Stanford University[6] indicate that about 20-25% of institutional support could be attributed to this type of costs, explaining half of the difference we find.

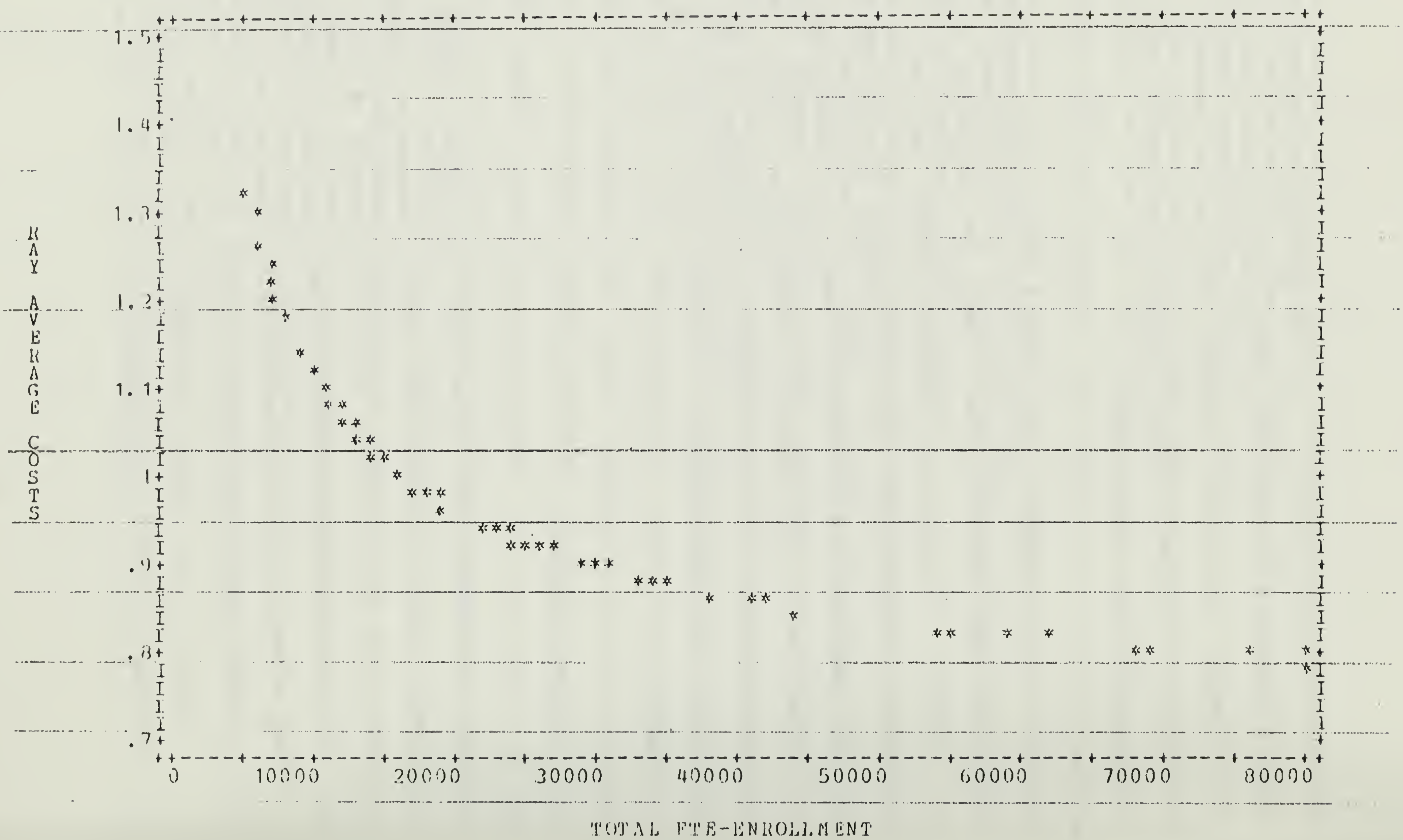
Note that the costs of revenue raising for state appropriations in the public sector , i.e. the costs of collecting taxes, are not included in our institutional support figures. Therefore differences between institutional support costs in the broadest sense in the private and public sector could be even smaller than suggested by our estimate of about 20%.

To facilitate interpretation of the cost functions, we calculated ray average (total) costs, as introduced in section II. Figure 1 displays ray average (total) costs as a function of total FTE-enrollment. For this figure, the ray has been defined by the output mix at the sample mean, i.e. every output combination along the ray is a multiple of the vector (12739, 3632, 654) in output space, i.e. all outputs are expanding at the same rate. Costs are normalized to 1 at the output vector of the sample mean.

(figure 1 here)

The ray average cost curve shows the typical L-shape known from single product average cost curves: decreasing average costs at the lower output range - therefore economies of scale - decreasing much less rapid at higher output levels and eventually increasing average costs or diseconomies of scale at very high outputs- actually beyond the output range of our sample. In our case, a minimum is obtained at very high output levels with μ = 18.6. Average costs at the minimum would be 20% less than at the sample

FIGURE 1

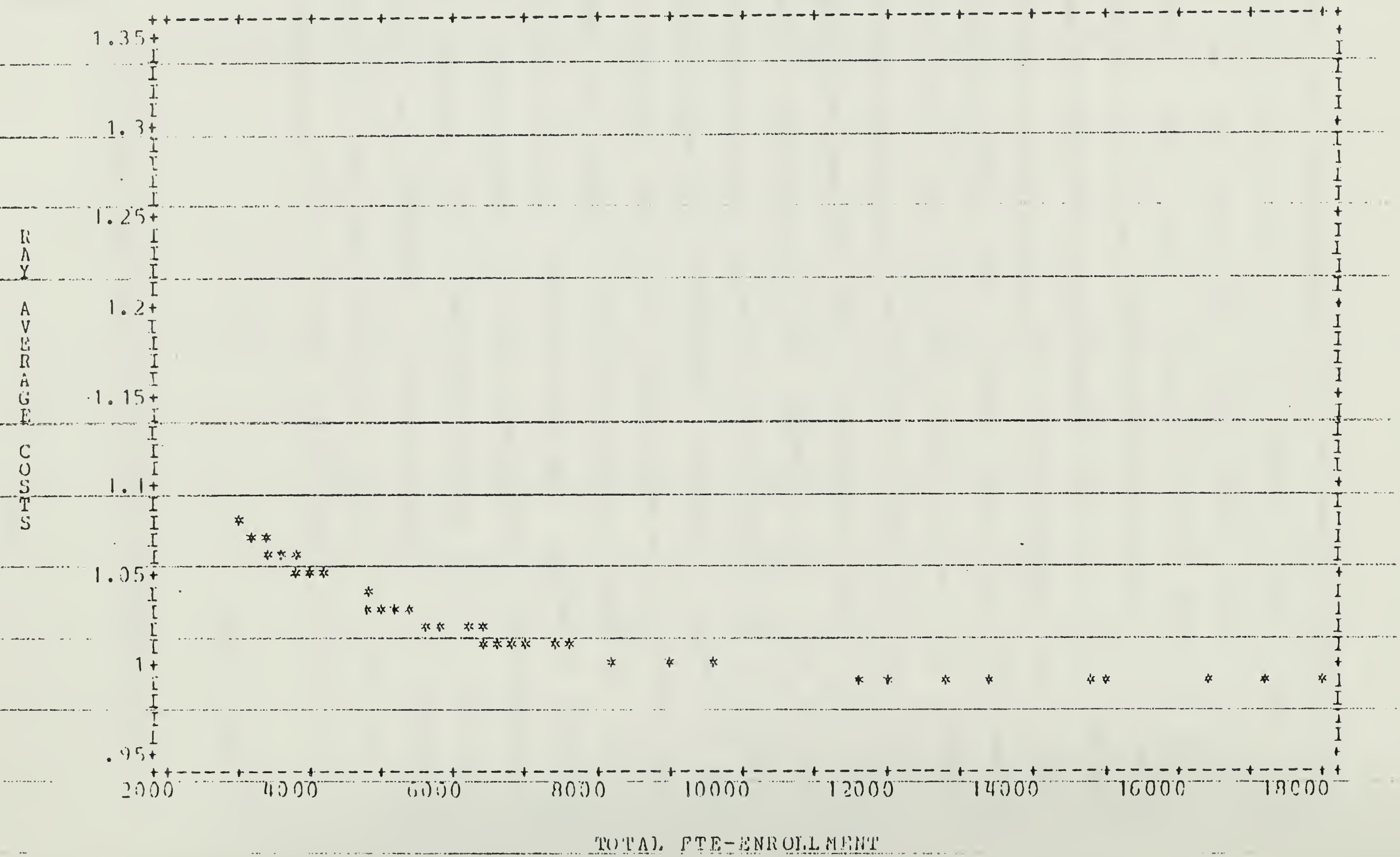

RAY AVERAGE COSTS
1.5
1.4
1.3
1.2
1.1
1
.9
.8
.7
0
10000
20000
30000
40000
50000
60000
70000
80000
TOTAL FTE-ENROLLMENT

mean. However, given the very slow decrease of ray average costs at higher outputs, already at μ = 3.3 ray average costs is within 10% of minimum average costs. This would imply an institution with an output vector of (42,039, 11,986, 2,158). In our sample there are institutions with graduate enrollment and publications in this range, but (FTE) undergraduate enrollment is never larger than 37,529 (compare table 1). The output vector in our sample which comes very close to this output is that of the University of Minnesota, which has the output vector (36,372, 12,325, 2,373). Apparently, for the largest universities there is some room for expanding undergraduate enrollment to reap additional economies of scale, but not much. Note, however, that the position of the minimum depends on the particular ray in output space. As we observed in our discussion of table A.1 (appendix), the output mix along the ray, defined by the sample mean, is not very different from that of the 'top public' research university. However, the 'top private' research university' <u>does</u> have an output mix quite different from the sample mean. Undergraduate and - to a lesser extent - graduate enrollment is much smaller than that of the top public research university while research output is comparable (see table 1). Ray average costs can also be calculated along the 'top private' ray and are shown in figure 2 as a function of FTE-enrollment.

(figure 2 here)

It is interesting to note that minimum average costs now are

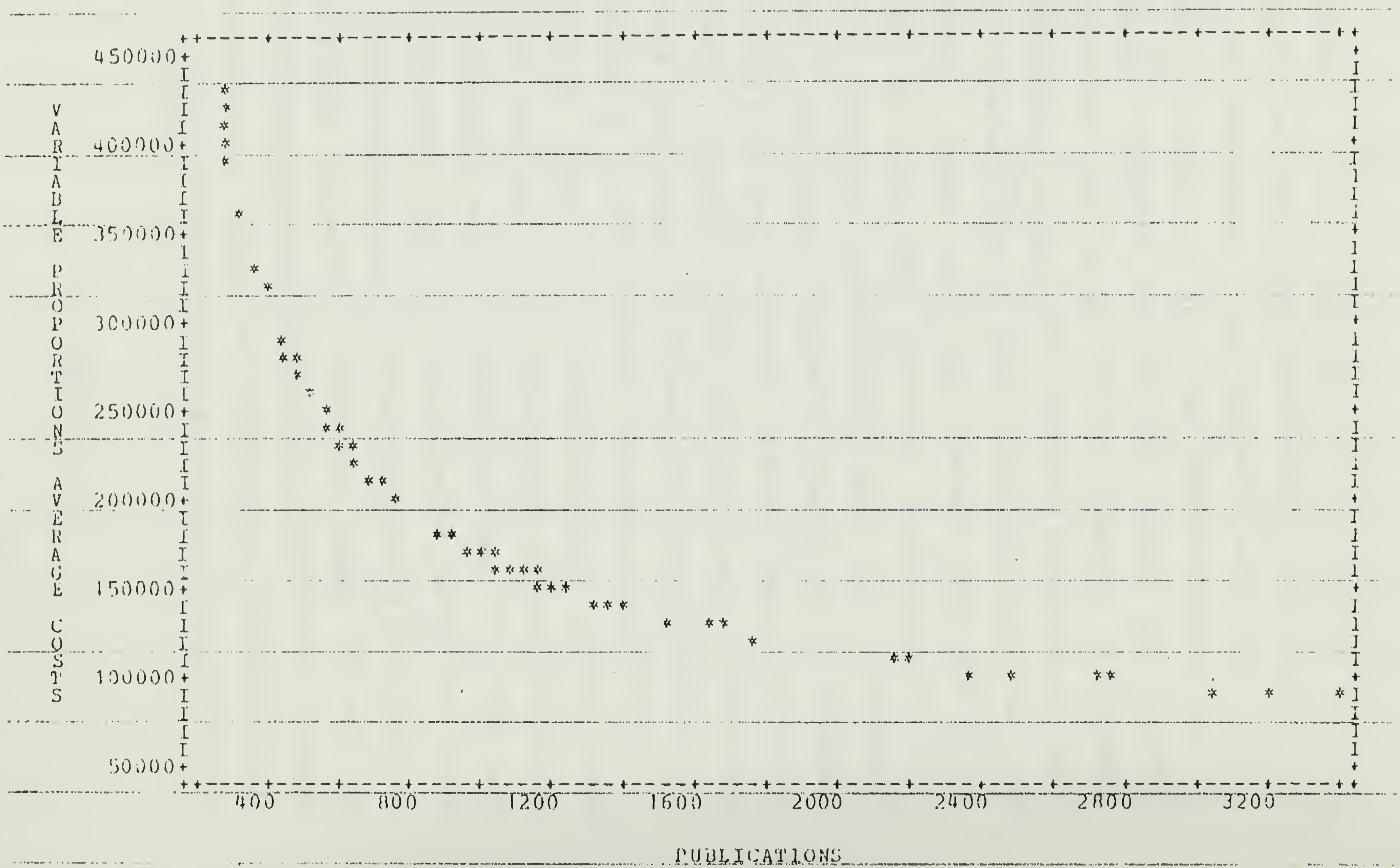
FIGURE 2


RAY AVERAGE COSTS
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
.95
2000
4000
6000
8000
10000
12000
14000
16000
18000
TOTAL FTE-ENROLLMENT

obtained at much smaller enrollment levels - typical between 10,000 and 15,000 FTE-enrollment than along the average or 'top public' ray. In fact, the top private universities are much closer to their minimum average costs than the top public universities provided each expands along the ray defined by <u>its own output proportions</u>. Apparently, there are at least two output mixes which are relatively efficient. The top public universities benefit from the large economies of scale for undergraduate instruction. At the same time, however, their large number of graduates can only be instructed at relatively high costs. The top private universities keep their undergraduate enrollment limited and therefore do not exploit economies of scale fully. However, by also having a small number of graduates, they avoid the relatively high costs of instructing this type of students. In both cases, the economies of scale for research are almost fully exploited.

The foregoing discussion indicates that it is instructive to study different expansion paths in output space. In particular, expanding one output, while keeping the others fixed, is an interesting option. We have calculated 'variable proportions average costs', as defined in section II, for the average institution, the typical top private and the typical top public research university. For the average institution considerable product-specific economies of scale can be achieved by expanding each of the three outputs separately. As an example, we present the variable proportions average cost curve for research output in figure 3.

FIGURE 3



450000
400000
350000
300000
250000
200000
150000
100000
50000
VARIABLE PROPORTIONS AVERAGE COSTS
400
800
1200
1600
2000
2400
2800
3200
PUBLICATIONS

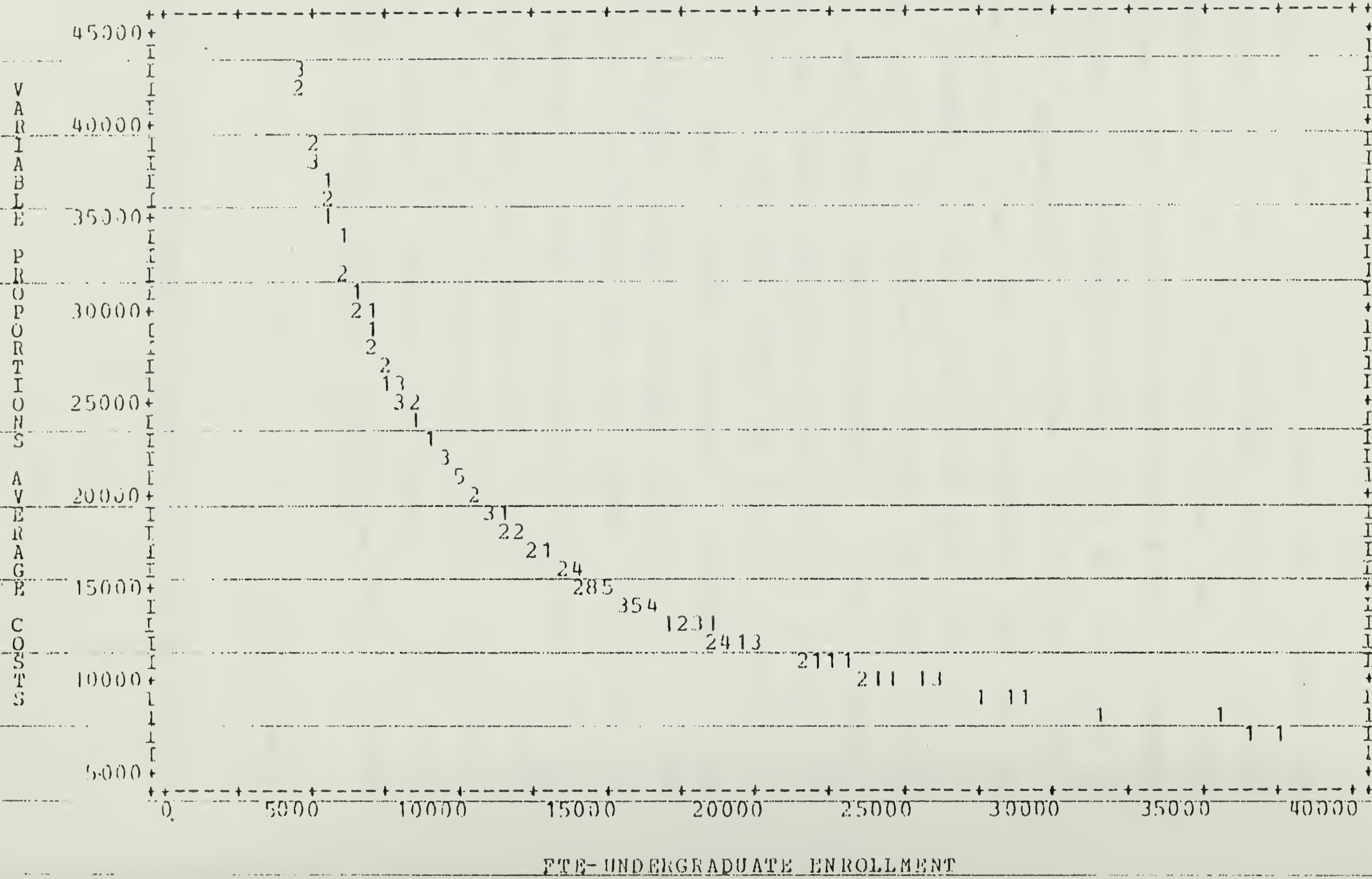
(figure 3 here)

The potential cost savings vary from 20% when expanding undergraduate or graduate enrollment to 100% when expanding research output for the average institution. The large product-specific economies of scale from expanding research output can be understood if we realize the very skewed distribution of publications, mentioned in section III, implying a select group of big producers and many small producers. The latter have a large potential for cost savings through economies of scale in research. However, if expanding research output is combined with large expansion of graduates as well - as with fixed output proportions - the relatively sharply rising costs of graduates reduce the cost savings considerably. For the top public research university product-specific economies of scale are limited, usually not larger than 10-20%, with expanding research output promising the largest efficiency gains. However, for the top private research university expanding undergraduate enrollment alone can generate large cost savings, up to 70% of current average costs per undergraduate, as illustrated in figure 4. This expansion path exploits the relatively smaller costs of undergraduate enrollment, and avoids the relatively expensive further expansion of graduate education and research.

(figure 4 here)

Expanding graduate enrollment or research output generates cost

FIGURE 4


VARIABLE PROPORTIONS AVERAGE COSTS
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
5000
10000
15000
20000
25000
30000
35000
40000
FTE-UNDERGRADUATE ENROLLMENT

savings comparable with the top public research universities. Of course, limiting undergraduate enrollment in the case of a top private research university can serve other objectives, such as prestige, outweighing the efficiency losses suggested by our results. For instance, limiting undergraduate enrollment, combined with a selective admission policy, may enhance perceived quality, although value added per student doe not justify it. These prestige-related outputs are only partially accounted for in our approach.

Finally, it is instructive to calculate the marginal cost of each output. At the sample mean the following marginal costs are obtained: $2,400 for a FTE-undergraduate student, $10,000 for a FTE-graduate student (therefore $4,100 per student for all students), and $75,000 per publication. The average revenue per student (adding undergraduates and graduates) in our sample is $3,700. Usually, the ratio of graduate to undergraduate tuition is much less than 4 to 1. Together with the marginal cost estimates this implies cross-subsidization of graduate instruction by undergraduate instruction (as suggested earlier by James (1978)). Of course, taxpayers and private sponsors subsidize all instruction as well.

A comparison of our results with other studies (see Leslie and Brinkman, 1986) reveals that others primarily focus on instruction outputs or instruction outputs plus research output, using research expenditure as a proxy. Brinkman (1981) studied a sample of 50 public and private universities. He approximated research output with research expenditure and allowed for a different undergraduate/graduate education mix. He found small economies of scale in instruction. Stommel (1978) found savings from economies of scale up to 20% for instruction in land-grant institutions, controlling for research expenditures and program mix, which seems to be in the range we find. McGuire et al (1988) studied the production of 'reputation' by research universities. Their results are difficult to compare to ours as they consider reputation to be the only output. In fact, their reputation index is derived from the same peer ratings as our (graduate) program quality index and shows a high correlation with the number of publications. Employing a Cobb-Douglas production function, they find diseconomies of scale in the production of reputation. This seems to be inconsistent with our results, even incorporating program quality as in our extended analysis in section V. We do find economies of scale with respect to quality improvement, although much smaller than for the other outputs. Note, however, that their sample only includes the 50 most prestigious institutions, that have exhausted to a large extent their potential economies of scale for research. Verry (1976) studied British universities, employing explicit research output measures, such as the number of publications. He did disaggregate different fields. He found no evidence for interaction terms between different outputs. However, graduate students are not used as teaching or research assistents in most British universities. He finds economies of scale for arts and social sciences, but not in the physical and life sciences. The aggregate economies of scale in his study are very small, which is contrary to our findings for U.S. research universities.

The study most closely related to ours is that of Cohn et al (1989). They estimate fixed-cost quadratic cost functions for two samples of four year institutions, 1,195 public and 692 private colleges and universities. The combined samples comprise almost all four year institutions. Although their sample covers a much wider range of institutions, their results can be compared to ours by focusing on their estimates of scale economies and scope economies for only the large institutions in their sample. Their average FTE-enrollment in the public sector is 4,840, as compared with 19,631 in our sample. Their average FTE-enrollment in the private sector is 1,960, as compared with 9,852 in our sample. A striking difference with our results is the small ray economies of scale they find in the public sector. Already at their sample mean these are almost fully exhausted, while we find ray economies of scale up to 50,000 FTE-enrollment. A possible explanation could be the small number of research universities in their sample, compared with the very large number of small institutions with little or no graduate instruction or research. This makes an accurate estimate of the cost function for high output levels difficult. Another explanation could be the poor performance of research expenditures as a research output proxy. We observed large differences in faculty productivity which are not reflected in the input measure[7]. Cohn et al however do find economies of scope over a large part of the output range. It is not clear from their results whether these should be attributed to joint production of undergraduate and graduate education, or to joint production of graduate education and research, or both. We find the most pronounced economies of scope between undergraduate and graduate education, which seems at least consistent with their results.

V Sensitivity Analysis

In this section we present some alternative estimates of the total cost function for research universities to test the sensitiviy of our main results to the choice of output indicators.

Our first alternative adds a program quality variable to the three output variables already included. The inclusion of additional, qualitative aspects of output is a very difficult task. On the instruction side one would like to have indications of the real value added during the teaching process. Although information on entrance qualifications of students is nationally available through student tests such as SAT, ACT and different graduate tests, comparable information on exit qualifications is lacking. For research, judging the quality of publications or citations across fields is a formidable task. However, the Conference Board Study on research-doctorate programs (Jones et al, 1982) which is our source for the number of publications also provides data on peer ratings. They are subjective judgments of peers in every field on program quality, expressed on a five point scale. The ratings are expected to include broad, qualitative considerations on program quality and research output.

Although the ratings are specifically obtained for graduate programs, we will assume that they represent a rough proxy of undergraduate program quality as well, given the involvement of faculty in both undergraduate and graduate instruction in most universities. The ratings, averaged over all programs within each institution, are therefore considered as a supplementary quality proxy for all outputs in our main analysis. Statistics on the ratings are included in table 1 (they are arbitrarily normalized following the Conference Board Study to a mean of 50 and standard deviation of 10 for the original sample in the survey). It is interesting that there is such a high correlation between the average quality variable and the number of publications in our sample (Pearson product-moment correlation of 0.88). Although this strenghtens confidence in the usefulness of our research output variable, it will introduce some collinearity in our estimates as well.

The quality proxy has been added as a fourth output proxy in the translog cost function. OLS-estimation results are presented in table 2.

(table 2 here)

The results shown in table 2 indicate that, as in our main analysis, the coefficients for the terms linear in (log) output smaller than 1. However, the coefficient of the quality proxy is much larger than those of the other outputs, indicating that

Table 2 Estimation results for total costs with undergraduate enrollment, graduate enrolment, publications and quality ratings as output

constant	a1	a2	a3	a4	a11	a22	a33	a44
-0.18* (4.0)	0.30* (4.7)	0.23* (3.5)	0.21* (3.6)	0.63 (1.9)	0.041 (1.2)	0.15* (2.3)	0.025 (0.87)	1.21 (0.76)

a12	a13	a14	a23	a24	a34	dummy medical school	dummy private control	R^2	scale elasticity
-0.18* (2.6)	0.10* (2.3)	-0.87* (2.8)	-0.10 (1.6)	0.61 (1.6)	-0.12 (0.32)	0.24* (5.5)	0.019 (0.74)	0.91	0.7

(absolute t-statistics in parentheses)
* = significant with p=0.05

costs are relatively sensitive to the quality level. In fact, if one wants to expand all outputs with the same percentage at the sample mean, costs increase more than output expands (the scale elasticity at the mean is less than 1). Note, however, that the quality variable is not additive: the average quality of a number of institutions of equal quality is the same as that of each separate institution. This implies that it is more useful to look at directions in output space with a given quality level - for instance the quality level one wants to maintain nationally.

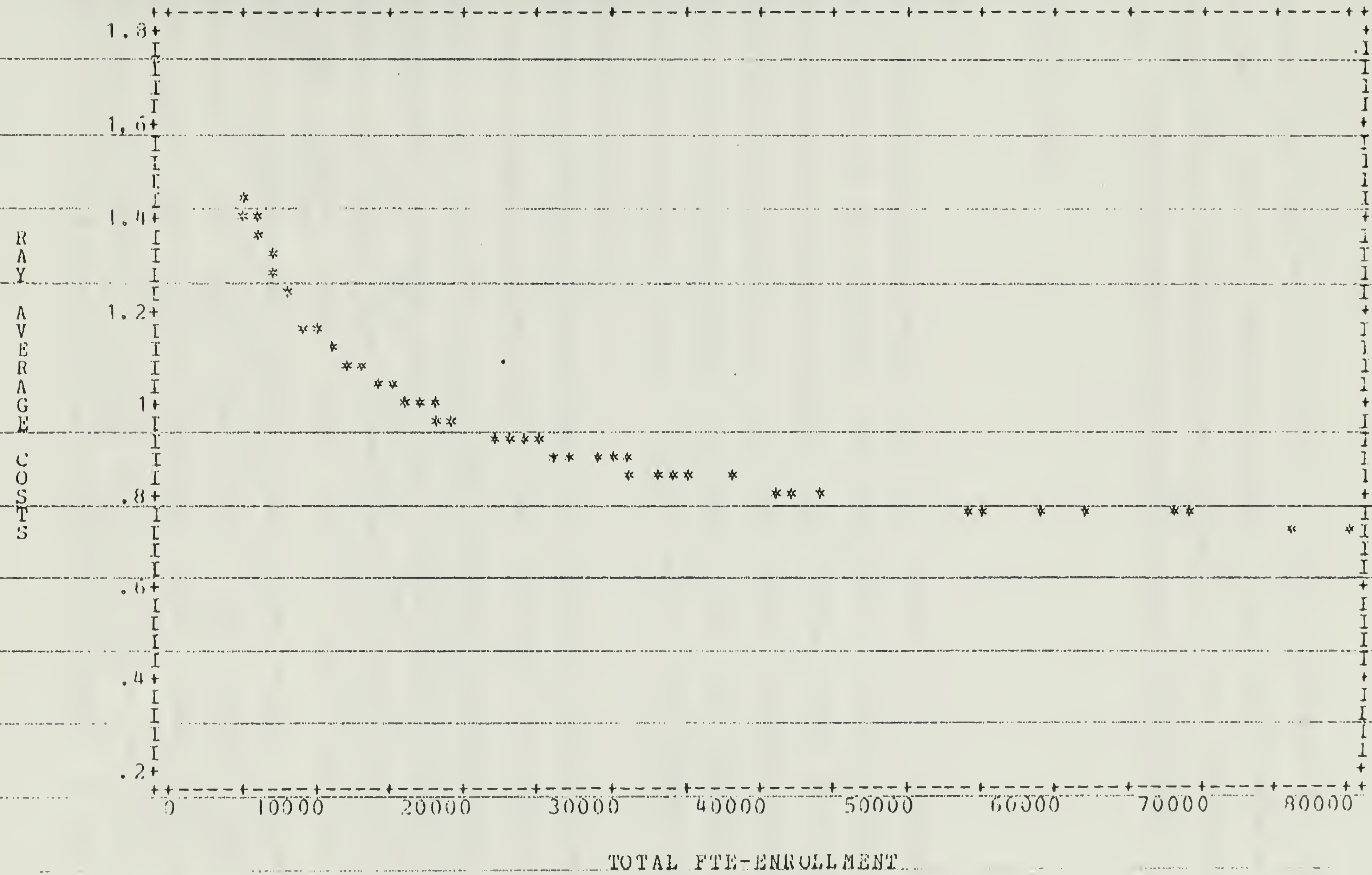
The interaction terms again reveal economies of scope to be obtained by supplying undergraduate and graduate education within the same institution.

However, within a given quality level, ray average costs curves are remarkable similar to those in the main analysis. As an example a ray average cost curve as a function of FTE-enrollment is presented in figure 5, keeping average quality at the sample mean. As in our main analysis, ray economies of scale are present up to high enrollment levels given the output mix of the sample mean.

(figure 5 here)

As a second alternative we consider earned undergraduate and graduate degrees respectively as alternative output measures to enrollment. These are supposedly closer to the final outputs of the education process. A drawback of these indicators is their

FIGURE 5


RAY AVERAGE COSTS
1.8
1.6
1.4
1.2
1
.8
.6
.4
.2
0
10000
20000
30000
40000
50000
60000
70000
80000
TOTAL FTE-ENROLLMENT

delayed relation with cost figures in an earlier year. Costs are incurred during the whole period of preparing for a degree. Given the essentially impossible task of allocating costs in different years to degrees obtained in a given year, we will simply relate total costs in our base year 1982-1983 to the number of degrees earned that year.

The estimated cost function with these education outputs, keeping the research output proxy identical to that in the main analysis, is given in table 3. Again, we limit the presentation of the results to total costs.

(table 3 here)

It shows that the structure of the total cost function is almost identical to that of this function in the main analysis. The coefficients of the linear terms are comparable to those in the main analysis and indicate sizable economies of scale at the sample mean. Also here, the quadratic terms in graduate instruction and research output are significant and positive, implying increasing unit costs at the higher output levels. Again, the interaction term between undergraduate and graduate degrees signals economies of scope through the joint production of undergraduate and graduate education.

The foregoing results illustrate the robustness of the outcomes of the main analysis and warrant some confidence in the global features of the estimated cost structure.

Table 3 Estimation results for total costs with earned undergraduate and graduate degrees and publications as outputs

constant	a1	a2	a3	a11	a22	a33
-0.13*	0.19*	0.21*	0.36*	0.055	0.16*	0.042*
(3.1)	(3.1)	(3.7)	(11.5)	(1.5)	(3.2)	(3.8)

a12	a13	a23	dummy medical school	dummy private control	R^2	scale elasticity
-0.21*	0.009	-0.037	0.27*	-0.013	0.88	1.32
(3.0)	(0.32)	(0.99)	(6.1)	(0.23)		

(absolute t-statistics in parentheses)
* = significant with p=0.05

VI Effects of State Regulation

In the foregoing analysis we controlled for the difference between public and private ownership of institutions. In this section we analyze the possible consequences of varying degrees of state regulation within the public sector. Using Volkwein's 1983 survey data we are able to differentiate between light, moderate and heavy state regulation within the public sector. We refer to Volkwein (1987) for details on the employed regulation measure. It is essentially a scale based on different items, related to the degree of campus autonomy in personnel and financial administrative practices. The Volkwein measure is available for 86 public doctorate granting universities. However, it turns out that <u>within</u> a state there are virtually no differences between the degree of regulation for different doctorate-granting institutions in that state. We applied Volkwein's measure to our larger sample of 147 universities by dividing the subsample of publicly controlled universities into three roughly equal groups. For each of the three groups dummy variables are included in our cost function estimates. A private university has the value zero on all three dummy variables. The results indicate <u>no</u> significant effect of the degree of state regulation, except in the case of institutional support costs. However, the coefficients of the dummy variables are not significantly different from each other.

This suggests that the type of control - public or private - is important for institutional support costs - as observed in the main analysis. The results are consistent with earlier studies by Volkwein for the public sector (see Volkwein, 1987, 1989). These studies use the same flexibility measure, but different indicators to measure the performance of institutions. Also, different outputs are not considered simultaneously as in the cost function approach.

Our results seem to confirm that there are no significant efficiency gains in the primary production process to be expected from state regulation of personnel and financial administrative practices. Those regulation measures include ceilings on the number of faculty positions, returning year-end surpluses, prescribing salary schedules, regulating investment decisions, et cetera. None of these seem to have any influence on the efficiency of the production process, with the possible exception of reducing institutional support costs somewhat. In fact, given the costs involved with implementing regulation on the part of the government- these are not accounted for in our cost figures - overall efficiency could be lowered.

VII Summary of Conclusions

Current techniques of analyzing multiple-product industries are applied to private and public research universities. The simultaneous production of instruction and research in the typical research university makes this type of analysis very useful. Three outputs are considered: undergraduate instruction, graduate instruction and research. The main analysis uses undergraduate full-time-equivalent enrollment, graduate full-time-equivalent enrollment and research publications. A robust and interesting pattern of relationships between costs and outputs for research universities is found.

The results indicate considerable economies of scale for the "average" institution in the primary process of producing teaching and research. There are even stronger economies of scale in the production of supportive services, like libraries, administrative support and student services. The least costly research university with output proportions corresponding to the "average" institution, turns out to be an institution with large undergraduate and graduate enrollment as well as a fairly large research output. Undergraduate enrollment is even somewhat larger than in any of the existing institutions. The large, prestigious public universities by and large resemble this profile. However, assuming the output mix of a small, private university, with small undergraduate enrollment and medium to large graduate enrollment and research output, the results are not clear cut. Simultaneous expansion of all outputs does not lead to sizable cost savings - implying that they are close to minimum ray average costs - but increasing undergraduate enrollment alone would generate considerable efficiency gains.

The effects of ownership and state regulation turn out to be surprisingly small. Only for institutional support - i.e. central administrative services - private sector costs seem to be higher than in the public sector. However, probably half of the difference can be explained by the costs of raising private funds in the private sector.

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Notes

*) Erasmus University Rotterdam, The Netherlands, University of Illinois at Urbana-Champaign, and State University of New York at Albany, respectively. The research for this article was done while the first author was a visiting scholar at Stanford University (School of Education) and the University of Illinois at Urbana-Champaign (Department of Economics) as a research fellow of the American Council of Learned Societies. Comments of Henry M. Levin, William F. Massy (Stanford University) and Rene Goudriaan (Erasmus University) in an earlier stage are gratefully acknowledged. We are indebted to Marie L. Richman (University of California at Irvine) and Charles N. Dold (University of Illinois) for assistance with the data collection.

1. We realize the importance of public service for many universities. There is, however, very limited nation-wide information on outputs of this type.

2. As an alternative, subsamples of public and private institutions respectively, have also been studied. A Chow-test revealed that the coefficients of the model for the two subsamples were not significantly different ($F_{11,125} = 1.2$).

3. Baumol et al (1982) use the term 'linear variety ray' to indicate linear trajectories not through the origin. Note that an expansion path in the plane defined by a fixed value of one of the outputs, expanding the two other outputs at fixed proportions, is another logical extension of ray average costs, which we will not explore here.

4. Alternative ways of investigating economies of scope are possible, comparing total costs when producing outputs jointly with those when producing each of the outputs separately. This would involve extrapolation of the translog cost function to zero output values where it is not defined. Although this can be circumvented by employing Box-Cox transformations of the variables, we prefer the more transparent approach of equation (8). The expression is essentially equal to the change in the output elasticity of costs for output i induced by a (percentual) unit change in output j.

5. Unfortunately, for some disciplines in the humanities, notably languages, publication data were not available. From the survey we know, however, that in 80% of the institutions less than 20% of total faculty is engaged in research in those disciplines. This implies that neglecting this part of the output has only a small effect on total output.

6. Private communication of J.P. Komodin.

7. Using the data of the survey on research-doctorate programs of Jones et al (1982) we obtained average faculty productivity as 2.0 articles per two-year period, with a standard deviation of 1.0 and varying between 0.2 and 6.1, indicating large differences in productivity.

Appendix

To give some idea of the typical values of the different variables in our sample, we present descriptive statistics in table A.1. To facilitate the interpretation of later results we also include some statistics on two subsets of our sample. They are designated 'top public' and 'top private' respectively. The subsample 'top public' is defined as those institutions having large undergraduate and graduate enrollment, as well as a large number of publications. Most prestigious, large public universities belong to this subsample of 21 institutions. We define "small", "average" and "large" values of the three output variables by ranking all institutions in order of increasing values for each of the outputs and constructing three groups of equal size. The subsample 'top private' is defined as those institutions having small undergraduate enrollment and a large number of publications. Most private, prestigious research universities belong to this small subsample of 11 institutions.

Although the output proportions of the 'top public' subsample do not differ very much from the sample mean (the 'top public' output vector is roughly twice the sample mean output vector), the output proportions of the 'top private' subsample do differ largely from the sample mean. In particular, they have almost the same number of graduates as the number of undergraduates, while the average institution and the 'top public' university have roughly three times as many undergraduates as graduates.

(table A.1 here)

Table A.1 shows the large variation in the level of different outputs. In particular the range of the number of publications is very large. The distribution of publications is very skewed, with the 22% 'top public' and 'top private' research universities producing 55% of the total number of publications.

Table A.1 Descriptive statistics on the sample of 147 doctorate-granting institutions

	mean	minimum	maximum
FTE-enrollment	16372	1605	48697
- 'top public'	32453		
- 'top private'	8973		
FTE-undergraduates	12739	588	37529
- 'top public'	25331		
- 'top private'	4679		
FTE-graduates	3632	414	12325
- 'top public'	7122		
- 'top private'	4294		
number of publications	654	8	3395
- 'top public'	1654		
- 'top private'	1659		
average program quality	46	28	69
undergraduate degrees	2537	83	8288
graduate degrees	1332	101	4951
total expenditures a) (mln dollars)	147	19	51
of which:			
instruction and research	97	8.5	330
academic support	15	1.0	84
student services	6.3	0.2	25
institutional support	14	1.9	48
operation and maintenance of plant	16	2.3	57
percentage institutions with a medical school	48		
percentage with private control	33		

a) minus income transfers and expenditures on public service