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Economies of scale and scope in higher education: a case of comprehensive universities

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Abstract

This study empirically estimates a multiple-product fixed total cost function and output relationship for comprehensive universities in the United States. Statistical results based on data for 158 private and 171 public *comprehensive universities* suggest that there are both economies of scale and economies of scope in higher education. However, product-specific economies of scope do not exist for all output levels and activities [JEL I22].

Keywords: Scale; Scope economies; Education cost

1. Introduction

Cost functions provide important information for producers to achieve efficiency in production. In the case of higher education, the question of economies of scale has been debated for over half of a century. Studies by Hashimoto and Cohn (1997), Koshal and Koshal (1995), Nelson and Heverth (1992), de Groot et al. (1991), Clotfelter et al. (1991), Getz et al. (1991), Hoenack (1990), Cohn et al. (1989), Brinkman (1990), Brinkman and Leslie (1986) and Friedman (1955) have conflicting conclusions regarding economies of scale. Our study explores different dimensions of economies of scale by estimating a multiple-product fixed total cost function. In the 1970s, two studies (Verry & Layard, 1975; Verry & Davies, 1976) also suggested the use of multiple-output total cost functions. However, recent studies also suggest that institutions of higher education produce multiple products (Jimenez, 1986; Cohn et al., 1989; Cohn, & Geske, 1990; Lloyd et al., 1993; Hashimoto & Cohn, 1997; Johnes, 1997). In addition, the quality of education, whether perceived or real, is different at different institutions (Koshal & Koshal, 1995). For example, one year of education at Amherst College is not the same as one year of education at Huntington College. Therefore, the cost and output relationship must make adjustments for various outputs and for quality variations among institutions. In addition to the single-output method, these studies had other drawbacks. First, some used the assumption that all the institutions in a cross-section analysis have the same objectives. It would be unreasonable to assume that the goal for all universities is to provide the same educational experience. One needs to account for such differences in relating cost to outputs. Second, most of the studies did not test their results for the presence of heteroscedasticity.

The purpose of this study is to estimate, for comprehensive universities, the long run, multiple-product total cost function by (1) controlling the quality of education for institutions that have similar objectives, and (2) applying various diagnostic checks to the estimated results.

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2. Model

In this study, we model our multiple-product cost function following the work of Baumol et al. (1982), Mayo (1984), Cohn et al. (1989), de Groot et al. (1991), Nelson and Heverth (1992), Dundar and Lewis (1995) and Hashimoto and Cohn (1997). Instead of a translog function, we assume that total cost (TC) of education output at an institution is represented by a flexible "fixed" cost quadratic function (FFCQ) of the following form:

$$\mathrm{TC} = a_0 + \sum_{i=1}^{k} a_i Q_i + \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{4} b_{ij} Q_i Q_j + c_1 D_\mathrm{G} + c_2 D_\mathrm{R} + d_1 C_1 + d_2 C_2 + d_3 C_3 + f\mathrm{PHD} + V \qquad (1)$$

where TC is the total cost of producing k products, a_0 is a constant, and a_i and b_{ij} are the coefficients associated with various output variables. Q_i is the output of the ith product. c_1 and c_2 are the coefficients of two dummy variables, D_G and D_R. D_G has a value of one if graduate output is non-zero, otherwise it takes a value of zero. Similarly, D_R is defined for the level of research activity. The terms d_1, d_2 and d_3 are the coefficients of the control program classification dummies C_1, C_2 and C_3. The Carnegie Commission has divided comprehensive universities into four classifications (Carnegie Foundation for the Advancement of Teaching, 1987). C_1 is a dummy if a university is public and over half of their baccalaureate degrees are awarded in two or more occupational or professional disciplines. C_3 is similarly defined for private universities. C_2 and C_4 are dummy variables for public and private institutions. In our study, C_4 represents the reference group. These institutions award more than half of their baccalaureate degrees in occupational or professional disciplines. In addition, they may also offer graduate education through the masters degree. C_1, C_2 and C_3 take values of one or zero according to an observation belonging to the particular classification. The coefficient f of the dummy PHD is for institutions that offer Ph.D. degrees. The PHD variable takes a value of one for institutions that offer Ph.D.; otherwise, it takes a value of zero. V is a random error term. The cost function of Eq. (1) permits us to estimate both economies of scale and economies of scope.

Generally, in the United States for higher education, there are three products: Q_U, undergraduate students; Q_G, graduate students; and Q_R, research activities. Following Baumol et al. (1982), Cohn and Geske (1990) and Hashimoto and Cohn (1997), we first define the average incremented cost (AIC) for undergraduate output as

$$\mathrm{AIC}_U = \frac{\mathrm{TC}\{Q_\mathrm{U},Q_\mathrm{G},Q_\mathrm{R}\} - \mathrm{TC}\{0,Q_\mathrm{G},Q_\mathrm{R}\}}{Q_\mathrm{U}} \qquad (2)$$

where $\mathrm{TC}\{Q_\mathrm{U}, Q_\mathrm{G}, Q_\mathrm{R}\}$ is the total costs of producing Q_U units of undergraduate students, Q_G units of graduate students and Q_R units of research. $\mathrm{TC}\{0, Q_\mathrm{G}, Q_\mathrm{R}\}$ is the total cost when output for product U is zero. Similarly, average incremental costs (AIC_G and AIC_R) for products G and R are defined. As in the case of a single product, the economies of scale are measured by the ratio of average to marginal costs. Economies of scale are said to exist if this ratio is greater than one. The product-specific economies of scale for product U is defined as

$$E_\mathrm{U} = \frac{\mathrm{AIC}_U}{\mathrm{MC}_U} \qquad (3)$$

where $\mathrm{MC}_\mathrm{U} = \partial\mathrm{TC}/\partial Q_\mathrm{U}$ is the marginal cost of producing product U. If E_U is greater (smaller) than one, economies (diseconomies) of scale are said to exist for the product U. Ray (overall) economies of scale (RE) may exist when the quantities of the product are increased proportionally. Ray economies of scale are defined as follows:

$$\mathrm{RE} = \frac{\mathrm{TC}\{Q_\mathrm{U},Q_\mathrm{G},Q_\mathrm{R}\}}{Q_\mathrm{U}\mathrm{MC}_U + Q_\mathrm{G}\mathrm{MC}_G + Q_\mathrm{R}\mathrm{MC}_R} \qquad (4)$$

Ray economies (diseconomies) of scale are said to exist when RE is greater (less) than one.

In any production process, economies of scope are present when there are cost efficiencies to be gained by joint production of multiple products, rather than by being produced separately. Following Dundar and Lewis (1995) and Hashimoto and Cohn (1997), economies of scope are divided into global and product-specific economies of scope. The degree of global economies (GE) of scope in the production of all products is defined as

$$\mathrm{GE} = \frac{\mathrm{TC}\{Q_\mathrm{U},0,0\} + \mathrm{TC}\{0,Q_\mathrm{G},0\} + \mathrm{TC}\{0,0,Q_\mathrm{R}\} - \mathrm{TC}\{Q_\mathrm{U},Q_\mathrm{G},Q_\mathrm{R}\}}{\mathrm{TC}\{Q_\mathrm{U},Q_\mathrm{G},Q_\mathrm{R}\}} \qquad (5)$$

Global economies (diseconomies) of scope are said to exist if GE is greater (less) than zero. Cost advantages due to production of each product jointly with the other outputs are called product-specific economies of scope (PSE). For example, for product U, this is given by

$$\mathrm{PSE}_U = \frac{\mathrm{TC}\{Q_\mathrm{U},0,0\} + \mathrm{TC}\{0,Q_\mathrm{G},Q_\mathrm{R}\} - \mathrm{TC}\{Q_\mathrm{U},Q_\mathrm{G},Q_\mathrm{R}\}}{\mathrm{TC}\{Q_\mathrm{U},Q_\mathrm{G},Q_\mathrm{R}\}} \qquad (6)$$

Product-specific economies (diseconomies) of scope associated with product U are said to exist if PSE_U is greater (less) than zero.

3. Data

The data pertain to comprehensive universities in the United States for the academic year 1990–91 and are collected from Management Ratios No. 7 for Colleges and Universities (1993)[1] and Barron's Profiles of American Colleges (1991). There are 635 comprehensive universities in the United States. However, a complete set of data for this analysis is available only for 329 of these institutions. In higher education, as pointed out by Cohn et al. (1989), there is no consensus on the appropriate measures of output. For the purpose of our analysis, we assume three outputs in higher education: (1) the number of full-time equivalent undergraduate students (Q_U), (2) the number of full-time equivalent graduate students (Q_G) and (3) the level of research activities measured in dollars (Q_R). Q_U includes all undergraduate students enrolled as freshmen, sophomores, juniors and seniors. Q_G includes students enrolled in masters-level and doctorate-level classes. We recognize that full-time equivalent enrollment (FTE) may not be the ideal measure of output, but it is an important improvement over just the absolute number of students used by some of the previous studies. Thus, in the absence of any better data, we have selected Q_U and Q_G in FTE units as our best measurements of the two teaching outputs.

In regards to the research output, the measurement of which is equally (or perhaps even more) controversial, the best measure available for this study is the amount of research funds that the faculties expend. The total cost variable used here (TC) is measured by a university's current expenditure. Definitions of variables used in this study, along with some basic descriptive statistics, are presented in Table 1.

For a measure of quality (Q), we use the average total scores on the Scholastic Aptitude Test (SAT) of entering freshmen[2]. The average SAT score signals the quality of an institution to prospective students and their future employers (Koshal et al., 1994; Koshal, & Koshal, 1995). To purchase a higher-quality educational experience, students/parents are willing to pay more at institutions with higher average SAT scores. In a study, Koshal and Koshal (1995) have shown that SAT and the quality index for colleges by *US News* and *World Reports* generate quite similar results in regression analysis.

4. Statistical results

Using the above data and applying the multiple regression technique, we first estimate the above quadratic multi-product total cost function. The results of this analysis are summarized in Table 2 as Eq. (7). The values in parentheses below the coefficients in Table 2 are t-values, Adj-R^2 is the coefficient of determination adjusted for the degrees of freedom. The F-ratio tests the overall fit of the equation. In Table 2, *** denotes a 1% level of significance, ** denotes a 5% level of significance, * denotes a 10% level of significance, and @ represents a 15% level of significance.

Statistically, the results of Eq. (7) in Table 2 are significant and the coefficients have the expected sign. These results suggest that the economies of scale exist in producing undergraduate, graduate student output and research activities. Yet, as explained below, this equation does not tell the entire story about the relationship between cost and output.

Jimenez (1986) and Hashimoto and Cohn (1997) suggest that including an index of input prices in the total cost function is important since, in a cross-section data set, the institutions are located all over the country. Each university may face different factor costs that would then influence total cost. Because faculty salaries, including instructional material, constitute a high proportion of the total cost of education, they are the most predominant factor cost. We re-estimate our cost function including average faculty salary plus instructional material per faculty member (FS). The results are summarized in Eq. (8) in Table 2. Since institutions can control total cost by varying the number of students per faculty member, we estimate Eq. (9) by adding class size (CSIZE). In Eq. (10) we add the SAT variable to test whether the quality of entering students has any effect upon total cost. Also included in Eq. (10) is a dummy for institutions that are primarily oriented toward engineering and medical education. To test for the presence of heteroscedacity, we apply the RESET test (Ramsey, 1969) to the residuals of Eqs (7) to (10). The test statistics indicate the presence of heteroscedacity. Therefore, the coefficients of these Eqs (7)–(10) are unbiased but inefficient, thus invalidating the test of significance.

Since public and private institutions have different objectives, we suggest estimating the cost function separately for private and public institutions. Following this approach, Eq. (11) summarizes the results only for private institutions while Eq. (12) gives results for public institutions. The RESET test suggests that the residuals of Eq. (11) as well as those of Eq. (12) are homoscedastic. Therefore, the coefficients of these equations are unbiased and efficient. The discussion that follows uses the results of Eqs (11) and (12).

In the following paragraphs, we provide various calculations of economies of scale and scope for Eqs (11) and

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[1] The Management Ratios data are from the US Department of Education, National Center for Education Statistics (1993).

[2] SAT scores are not available for a few institutions. By using the data of Langston and Watkins (1980) for SAT equivalencies of ACT scores, Harford and Marcus (1986) suggest the following regression equation for converting ACT scores to SAT scores:

$$\mathrm{SAT} = 309.91 + 14.89\mathrm{ACT} + 0.226(\mathrm{ACT})^2 + 0.0086(\mathrm{ACT})^3$$

Using this equation, we estimate SAT scores for the institutions for which the only ACT scores are reported.

Table 1
Definition of variable and summary statistics

Variable	Description	Mean/standard deviation		
		all: $n = 329$	private: $n = 158$	public: $n = 171$
TC	Total cost in millions of dollars	42.1617	32.1411	51.4205
		(32.0721)	(26.1320)	(34.2698)
Q_U	Undergraduate FTE in thousands	3.9487	2.2432	5.5253
		(3.0417)	(1.2773)	(3.3374)
Q_G	Graduate FTE in thousands	0.8692	0.59402	1.1235
		(1.0789)	(0.7693)	(1.2506)
Q_R	Research expenditure in millions of dollars	0.9891	0.4843	1.4556
		(3.2618)	(2.8256)	(3.5634)
Q_U^2	(Undergraduate FTE)^2	24.8160	6.6491	41.6018
		(43.1002)	(9.1335)	(54.0085)
Q_G^2	(Graduate FTE)^2	1.9161	0.9409	2.8171
		(5.2497)	(2.6016)	(6.7248)
Q_R^2	(Research expenditure)^2	11.5851	8.1682	14.7422
		(82.7928)	(93.7948)	(71.2729)
SAT	Average SAT score	881.3071	925.8994	840.1050
		(127.5664)	(108.7191)	(130.1000)
CSIZE	Average class size	16.1641	15.0380	17.2047
		(3.8505)	(3.6256)	(3.7682)
SF	Average faculty salary in hundreds of dollars	55.7872	54.7603	56.7361
		(15.5623)	(16.1070)	(15.0263)
SF^2	Square of average faculty salary in hundreds of square dollars	3353.67	3256.49	3443.45
		(2114.63)	(2131.48)	(2101.20)
$Q_U \cdot Q_G$		5.5142	1.8899	8.8629
		(12.3984)	(3.9933)	(16.0740)
$Q_U \cdot Q_R$		6.2291	2.3390	9.823
		(24.3170)	(16.7828)	(29.2183)
$Q_G \cdot Q_R$		1.9282	1.0294	2.7586
		(9.2781)	(8.4762)	(9.9181)
$Q_U \cdot$SF		237.7131	128.4762	338.6453
		(242.7062)	(106.3684)	(286.1256)
$Q_G \cdot$SF		52.8275	34.2992	69.9473
		(77.8858)	(47.8555)	(94.7381)
$Q_R \cdot$SF		59.3355	35.4181	81.4345
		(206.6608)	(208.4771)	(203.0780)

(12). Thus, our discussion will mainly concentrate on comparing the private education costs with those of public education costs.

In Tables 3 and 4, we provide the marginal cost of each product for different levels of output along a proportional output ray. These marginal cost values are calculated at the mean values of the relevant variables. An examination of the estimates in Tables 3 and 4 for private institutions suggests that, for all levels of output, the marginal cost of graduate FTE is higher than that for undergraduate FTE. For public institutions, the marginal cost for graduate output is higher than the undergraduate marginal cost only at and beyond the mean value of output. This is consistent with the practice at many public higher educational institutions of offering most of the master-level courses combined with undergraduate level, especially in the cases where graduate output is low. The marginal cost for undergraduate FTE declines as output level increases. On the other hand, the marginal cost of graduate FTE and research activity increases as output level increases. For example, in the case of private institutions, the marginal cost for graduate FTE is US$12 537 at the 50% level of mean output and US$18 526 for a 300% level of mean output.

For public educational institutions in Table 4, the marginal cost for graduate FTE varies between US$6540 and US$7945. Marginal cost for public undergraduate FTE ranges between US$3706 and US$7259, depending on the level of output. For all output levels, it is no surprise to note that the marginal cost at private educational insti-

Table 2
Summary of regression results

	Eq. (7) All	Eq. (8) All	Eq. (9) All	Eq. (10) All	Eq. (11) Private	Eq. (12) Public
Intercept	0.8468	−9.4028	13.7689	3.8892	5.1249	3.6680
	(0.390)	(−1.682)	(3.439)	(0.931)	(0.810)	(0.582)
Q_U	9.0781	6.8539	8.8248	6.4416	7.7825	5.0533
	(9.029)***	(6.507)***	(10.074)***	(8.337)***	(3.065)***	(4.874)***
Q_G	12.0971	10.7788	8.1411	10.2920	6.5403	6.3050
	(6.231)***	(4.482)***	(4.104)***	(6.086)***	(1.795)*	(2.713)***
Q_R	3.6981	1.0683	0.3726	1.207	2.8879	2.4871
	(5.087)***	(1.245)	(0.529)	(2.000)**	(1.076)	(2.479)**
$(Q_U)^2$	−0.1839	−0.0895	−0.1740	−0.1781	−0.4858	−0.1448
	(−2.286)**	(−1.336)	(−3.165)***	(−3.801)***	(−1.854)*	(−2.395)**
$(Q_G)^2$	−1.3712	−0.7295	−0.0804	0.0127	−2.1964	0.1985
	(−2.392)**	(−1.579)$^{@}$	(−0.211)	(0.039)	(−2.532)**	(0.534)
$(Q_R)^2$	−0.0484	−0.0689	−0.02807	0.0011	−0.1234	−0.0183
	(−2.071)**	(−3.487)***	(−1.702)*	(0.078)	(−1.325)	(−0.821)
$Q_U \cdot Q_G$	0.5455	0.1904	0.0608	0.01747	1.7874	0.0689
	(1.717)*	(0.697)	(0.271)	(0.092)	(2.643)***	(0.298)
$Q_U \cdot Q_R$	−0.1654	−0.1320	−0.0448	0.0106	−0.5360	0.0698
	(−2.177)**	(−2.163)**	(−0.888)	(0.245)	(−0.750)	(1.256)
$Q_G \cdot Q_R$	−0.1415	0.0259	−0.0885	−0.2230	2.2720	−0.1820
	(−2.040)**	(0.143)	(−0.592)	(−1.753)**	(1.807)*	(−1.188)
SF	—	−0.2319	0.1198	0.4936	0.0939	0.9580
		(−1.491)$^{@}$	(0.931)	(4.254)***	(0.564)	(5.093)***
SF^2	—	0.0042	0.0028	−0.0015	0.0005	−0.0051
		(2.946)**	(2.352)**	(−1.353)	(0.334)	(−2.701)***
$Q_U \cdot SF$	—	0.0046	0.0047	0.0399	0.0612	0.0514
		(0.334)	(0.415)	(3.937)***	(1.847)*	(3.169)***
$Q_G \cdot SF$	—	0.0070	0.0064	−0.0196	0.0664	−0.0008
		(0.180)	(0.202)	(−0.725)	(1.162)	(−0.021)
$Q_R \cdot SF$	—	0.0405	0.0290	0.0029	−0.0277	−0.0199
		(3.199)***	(2.793)***	(0.312)	(−0.833)	(−1.304)
CSIZE	—	—	−1.6507	−1.6387	−1.3022	−2.0384
			(−12.872)***	(−14.664)***	(−9.520)***	(−12.396)***
SAT	—	—	—	0.0039	0.0103	−0.0031
				(1.245)	(2.364)**	(−0.758)
PHD	7.2315	7.0583	5.5079	5.3084	2.1627	4.7485
	(3.021)***	(3.717)***	(3.540)***	(4.013)***	(1.515)$^{@}$	(2.060)**
D_R	3.3001	3.2653	2.5294	1.9919	2.1999	−0.0451
	(2.040)**	(2.489)**	(2.348)**	(2.180)**	(2.115)**	(−0.029)
D_G	−0.0299	0.3432	−1.3239	−1.8027	−1.4147	−1.5402
	(−0.015)	(0.219)	(−1.028)	(−1.648)$^{@}$	(−1.193)	(−0.887)
C_1	−13.6192	−7.7822	−7.3364	−5.2131	–	0.0012
	(−5.298)***	(−3.686)***	(−4.313)***	(−3.532)***		(0.001)
C_2	−5.9198	−2.2531	−2.3315	−1.5060	–	—
	(−1.910)*	(−0.896)	(−1.153)	(−0.862)		
C_3	3.4682	2.9336	2.9578	1.9049	−1.7952	—
	(1.677)*	(1.790)*	(2.211)**	(1.669)*	(−1.505)$^{@}$	
Dummy	–	–	–	32.2958	27.7343	—
				(11.027)***	(9.392)***	
Adj-R^2	0.8816	0.9268	0.9508	0.9697	0.9672	0.9682
(*F*-ratio)	{163.89}***	{203.22}***	{302.73}***	{390.76}***	{221.33}***	{259.79}***
n	329	329	329	329	158	171

Notes: Where applicable one tail test is applied.
$^{@}$ denotes 15% level of significance; * denotes 10% level of significance; ** denotes 5% level of significance; *** denotes 1% level of significance.

Table 3
Marginal cost estimates for private institutions (MC in dollars)

% of output mean	MC_U	MC_G	MC_G/MC_U ratio	MC_R
50	10 449	12 537	1.20	1.39
100	9761	14 510	1.49	1.40
150	9073	16 095	1.77	1.41
200	8385	17 293	2.06	1.43
250	7697	18 103	2.35	1.44
300	7009	18 526	2.64	1.46

Notes: MC_U—marginal cost of undergraduate education; MC_G—marginal cost of graduate education; MC_R—marginal cost of research activities.

Table 4
Marginal cost estimates for public institutions (MC in dollars)

% of output mean	MC_U	MC_G	MC_G/MC_U ratio	MC_R
50	7259	6541	0.90	1.42
100	6548	6821	1.04	1.49
150	5838	7102	1.22	1.55
200	5127	7383	1.44	1.61
250	4417	7664	1.74	1.68
300	3706	7945	2.14	1.74

Notes: MC_U—marginal cost of undergraduate education; MC_G—marginal cost of graduate education; MC_R—marginal cost of research activities.

Table 5
Average costs for private institutions (AIC in dollars)

% of output mean	AIC_U	AIC_G	AIC_G/AIC_U ratio	AIC_R
50	10 993	7315	0.67	10.50
100	10 850	11 598	1.07	6.00
150	10 706	14 294	1.34	4.53
200	10 563	16 593	1.57	3.82
250	10 419	18 733	1.80	3.41
300	10 276	20 793	2.02	3.15

Notes: AIC_U—average integrated cost of undergraduate education; AIC_G—average integrated cost of graduate education; AIC_R—average integrated cost of research activities.

Table 6
Average integrated cost for public institutions (AIC in dollars)

% of output mean	AIC_U	AIC_G	AIC_G/AIC_U ratio	AIC_R
50	7659	12 140	1.59	1.37
100	7348	9454	1.29	1.48
150	7038	8672	1.23	1.57
200	6727	8365	1.24	1.65
250	6417	8249	1.29	1.73
300	6106	8228	1.35	1.81

Notes: AIC_U—average integrated cost of undergraduate education; AIC_G—average integrated cost of graduate education; AIC_R—average integrated cost of research activities.

tutions is higher than at public educational institutions. However, it is interesting to observe that the marginal cost of graduate FTE at private educational institutions is more than double the marginal cost at public institutions. The research marginal cost at both private and public institutions increases with the output level. The marginal cost of research at the public institutions is slightly higher compared with the marginal cost at private institutions.

For the total cost function as formulated above, the estimated mean value of the outputs cross marginal cost (CMC) are defined as follows:

$$\mathrm{CMC}_{UG} = \frac{\partial^2(\mathrm{TC})}{\partial Q_{\mathrm{U}}\partial Q_{\mathrm{G}}}, \quad \mathrm{CMC}_{UR} = \frac{\partial^2(\mathrm{TC})}{\partial Q_{\mathrm{U}}\partial Q_{\mathrm{R}}},$$
$$\mathrm{CMC}_{GR} = \frac{\partial^2(\mathrm{TC})}{\partial Q_{\mathrm{G}}\partial Q_{\mathrm{R}}}, \quad \mathrm{CMC}_{UFS} = \frac{\partial^2(\mathrm{TC})}{\partial Q_{\mathrm{U}}\partial Q_{\mathrm{FS}}}, \tag{13}$$
$$\mathrm{CMC}_{GFS} = \frac{\partial^2(\mathrm{TC})}{\partial Q_{\mathrm{G}}\partial Q_{\mathrm{FS}}}, \quad \mathrm{CMC}_{RFS} = \frac{\partial^2(\mathrm{TC})}{\partial Q_{\mathrm{R}}\partial Q_{\mathrm{FS}}}$$

It is obvious that the values of $\mathrm{CMC}_{\mathrm{UG}}$, $\mathrm{CMC}_{\mathrm{UR}}$, $\mathrm{CMC}_{\mathrm{GR}}$, $\mathrm{CMC}_{\mathrm{UFS}}$, $\mathrm{CMC}_{\mathrm{GFS}}$ and $\mathrm{CMC}_{\mathrm{RFS}}$, the cross-marginal products, are given by the coefficients of the corresponding interaction terms in Eqs (11) and (12), Table 2. A negative sign of the coefficients would imply that there is cost complementarity. A review of the results in Table 2 suggests that for private institutions, the coefficient of interaction terms for $(Q_G \cdot Q_R)$ and $(Q_R \cdot \mathrm{FS})$ only have a negative sign. These terms are statistically insignificant. On the other hand, the coefficients of $(Q_U \cdot Q_R)$ and $(Q_G \cdot Q_R)$ are positive and are significant at least at the 5% level. This result implies substitutability between Q_U and Q_R and also between Q_G and Q_R. For public instituitions, the negative sign is for the coefficient of interaction term $(Q_U \cdot Q_R)$, $(Q_G \cdot \mathrm{FS})$ and $(Q_R \cdot \mathrm{FS})$. The coefficients of these terms are not statistically significant.

A major shortcoming with the multiple product case is that there is no direct analogy to the the "average cost" concept in the single output case (Cohn et al., 1989; Hashimoto & Cohn, 1997). However, as discussed earlier, the nearest analogy is provided by the average incremental cost (AIC). These values are listed in Tables 5 and 6. As is obvious from the marginal cost values for all output levels, the values of average incremental cost for graduate FTE is higher than the undergraduate FTE average incremental cost.

An examination of the results in Tables 5 and 6 sug-

Table 7
Ray economies of scale for private institutions

% of output mean	E_{RAY}	E_U	E_G	E_R
50	0.65	1.05	0.58	7.58
100	1.22	1.11	0.80	4.29
150	1.81	1.18	0.89	3.21
200	2.43	1.26	0.96	2.67
250	3.11	1.35	1.03	2.36
300	3.87	1.47	1.12	2.16

Notes: E_{RAY}—Ray economies of scale; E_U—undergraduate education economies of scale; E_G—graduate education economies of scale; E_R—research activity economies of scale.

gests that, for private as well as public institutions, the AIC for undergraduate FTE declines as output level increases. For graduate FTE outcome is quite different. Graduate AIC at private institutions increases as output level increases, but at public institutions this declines with the increase of output level.

The estimates for the values of ray and product-specific economies of scale are summarized in Tables 7 and 8. Ray economies and product-specific economies of scale occur when the scale coefficient is greater than one. The results indicate product-specific economies of scale for all products except graduate education at private institutions. Reviewing the values in Tables 7 and 8, one realizes that ray economies only apply when the output level is equal to or greater than the mean values of output for public and private institutions. Both undergraduate and graduate education at public institutions exhibit product-specific economies of scale. For private institutions, product-specific economies of scale are present for undergraduate education, but graduate education has diseconomies up to 200% of mean output level. It is interesting to note that research output exhibits economies of scale for private institutions and almost constant returns to scale for public institutions.

Table 8
Ray economies of scale for public institutions

% of output mean	E_{RAY}	E_U	E_G	E_R
50	0.59	1.06	1.86	0.97
100	1.07	1.12	1.39	1.00
150	1.57	1.21	1.22	1.01
200	2.07	1.31	1.13	1.02
250	2.59	1.45	1.08	1.03
300	3.12	1.65	1.04	1.04

Notes: E_{RAY}—Ray economies of scale; E_U—undergraduate education economies of scale; E_G—graduate education economies of scale; E_R—research activity economies of scale.

Table 9
Economies of scope for private institutions

% of output mean	ESG	ES_U	ES_G	ES_R
50	1.13	−0.03	0.07	1.17
100	0.57	−0.06	−0.03	0.64
150	0.33	−0.08	−0.10	0.44
200	0.19	−0.12	−0.16	0.34
250	0.08	−0.15	−0.22	0.28
300	−0.01	−0.18	−0.28	0.23

Notes: ESG—global economies of scale; ES_U—economies of scope for undergraduate education; ES_G—economies of scope for graduate education; ES_R—economies of scope for research activities.

Tables 9 and 10 list values of the coefficient of scope economies. As stated earlier, scope economies exist as long as the coefficient of economies of scope is positive. In Tables 9 and 10, for private as well as public institutions, the coefficient of global economies of scope are positive except at 300% of the mean level of output for private institutions. Therefore, global economies of scope exist for the output range under consideration. The results for product-specific economies of scope are mixed. For research activity there are product-specific economies of scope at both private and public institutions. These results imply product-specific diseconomies of scope for undergraduate and graduate education at private comprehensive universities. The results in Table 10 indicate product-specific diseconomies for undergraduate education only at an output level of 250% or higher of mean output. For illustration purposes, it is interesting to observe that for all outputs at 200% of their respective mean, the cost of production at comprehensive private universities that specialize in only one output is 19 times higher than it is for a university producing all three out-

Table 10
Economies of scope for public institutions

% of output mean	ESG	ES_U	ES_G	ES_R
50	0.38	0.11	0.12	0.26
100	0.21	0.05	0.07	0.15
150	0.14	0.02	0.05	0.10
200	0.10	0.00	0.03	0.08
250	0.07	−0.02	0.03	0.06
300	0.05	−0.04	0.02	0.05

Notes: ESG—global economies of scale; ES_U—economies of scope for undergraduate education; ES_G—economies of scope for graduate education; ES_R—economies of scope for research activities.

puts. The corresponding figure for public institutions is 10.

5. Conclusions

Using data for 158 comprehensive private universities and 171 comprehensive public universities in the United States, this paper shows that it is possible to study economies of scale, product-specific economies of scale, ray economies of scale and global economies of scope. The main findings of our study are as follows.

1. Holding all other things as being equal, the overall total cost is affected by class size. For example, on the average, if class size is increased by one student (FTE), ceteris peribus the overall total cost would decrease by US$1.30 million at public institutions and by US$2.04 million at private institutions.
2. Other things being equal, the quality of entering students as measured by SAT scores do affect total cost at private comprehensive universities.
3. Public institutions which offer a Ph.D. degree will, on average, have US$4.75 million in additional costs. However, at private institutions, the addition to total cost is US$2.16 million. This may be due to the fact that at private institutions, more of the costs related to doctorate programs are absorbed through research grants.
4. As observed by Nelson and Heverth (1992), Hashimoto and Cohn (1997) and in our study also, the marginal cost of graduate education is higher than that of undergraduate education teaching. However, our results for comprehensive universities implies that the ratio (MU_G/MU_U) is much smaller compared with previous studies. In our study, this ratio varies between 1.20 and 2.64 for private institutions and between 0.90 and 2.14 for public institutions, compared with 3.0 to 5.3 in Nelson and Heverth's study for the United States, and 50 in Hashimoto and Cohn's study for Japanese private universities.
5. Our results indicate that ray economies of scale exist for comprehensive universities. These results are quite similar to the findings by Cohn et al. (1989), Dundar and Lewis (1995) and Hashimoto and Cohn (1997). It may be noted that de Groot et al. (1991) found ray economies of scale for the large public research universities. Similarly Cohn et al. (1989) observed ray economies for the smaller universities.
6. As in the previous studies, our statistical estimates for product-specific economies of scale for undergraduate and graduate education indicate mixed conclusions. Our results imply that there are product-specific economies of scale for research at private institutions. For research at public institutions, after reviewing Table 8, one finds constant product-specific returns to scale. In earlier studies, the results for undergraduate and graduate product-specific economies of scale have varied. For example, Cohn et al. (1989) reported product-specific economies of scale for graduate education and research in the public sector but no product-specific economies of scale for any of their output in the private sector. A study by Dundar and Lewis (1995) indicates the presence of product-specific economies of scale for research but not for undergraduate and graduate education. They observed similar economies for all fields except for engineering. A recent study of Japanese universities by Hashimoto and Cohn (1997) concludes that there are product-specific economies of scale for undergraduate and graduate education for small universities and that product-specific economies of scale exist for research in large universities. According to our results, there are product-specific economies for undergraduate and graduate education at public universities for all levels of output. At private institutions, undergraduate education exhibits product-specific economies of scale at all levels. However, in the case of graduate education at private institutions, product-specific economies of scale are exhibited only at and beyond the 250% level of output.
7. Our results indicate that global economies of scope exist for the entire output range except at the 300% level output for private institutions. For research, product-specific economies of scope exist for all output levels at public and private institutions. The results for undergraduate and graduate education suggest both product-specific economies and diseconomies of scope depending on the output level as well as the type of institution. Overall, as regards to scope economies, our results imply conclusions similar to those reached in earlier studies by Dundar and Lewis (1995), Cohn et al. (1989), Nelson and Heverth (1992) and Hashimoto and Cohn (1997).

Overall, our results suggest that comprehensive universities in the United States can reap benefits from both scale and scope economies. Large comprehensive universities appear to be more cost-efficient. Of course, beyond some level of output, inefficiencies may exist. But, based on the results in this study, we are not able to pinpoint any optimum level of output. In the future, with the availability of more refined data, many of the limitations of this study could be overcome and researchers might be able to estimate an optimum size for private and public comprehensive universities.

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References

Barron's Profiles of American Colleges (1991). Barron's Educational Series, Inc. New York.

Baumol, W. J., Panzar, J. C., & Willig, R. D. (1982). *Contestable markets and the theory of industry structure*. New York: Harcourt Brace Jovanovich.

Brinkman, P. T. (1990). Higher education cost functions. In S. A. Hoenack, & E. L. Collins (Eds.), *The economies of American universities—management, operations, and fiscal environment* (pp. 107–128). Albany, NY: State University of New York Press.

Brinkman, P. T., & Leslie, L. L. (1986). Economies of scale in higher education: sixty years of research. *Review of Higher Education*, *10*, 1–28.

Carnegie Foundation for the Advancement of Teaching (1987). *A classification of institutions in higher education*. Princeton, NJ: Princeton University Press.

Clotfelter, C., Ehrenberg, R., Getz, M., & Siegfried, J. (1991). *Economic challenges in higher education*. Chicago, IL: University of Chicago Press.

Cohn, E., & Geske, T. G. (1990). *The economics of education* (3rd ed.). Oxford: Pergamon Press.

Cohn, E., Rhine, S. L. W., & Santos, M. C. (1989). Institutions of higher education as multi-product firms: economies of scale and scope. *Review of Economics and Statistics*, *71*, 284–290.

De Groot, H., McMahon, W. W., & Volkwein, J. F. (1991). The cost structure of American research universities. *Review of Economics and Statistics*, *73*, 424–431.

Dundar, H., & Lewis, D. R. (1995). Departmental productivity in American universities: economies of scale and scope. *Economics of Education Review*, *14*, 199–244.

Friedman, M. (1955). A survey of the empirical evidence of economies of scale. Comment in *A Conference of the Universities National Bureau Committee for Economic Research, Business Concentration and Price Policy* (pp. 230–238). Princeton, NJ: Princeton University Press.

Getz, M., Siegfried, J. J., & Zhang, H. (1991). Estimating economies of scale in higher education. *Economic Letters*, *37*, 203–208.

Harford, J. D., & Marcus, R. D. (1986). Tuition and U.S. private college characteristics: the hedonic approach. *Economics of Education*, *5*, 415–430.

Hashimoto, K., & Cohn, E. (1997). Economies of scale and scope in Japanese private universities. *Education Economics*, *5*, 107–116.

Hoenack, S. A. (1990). An economist's perspective on costs within higher education institutions. In S. A. Hoenack, & E. L. Collins (Eds.), *The economics of American universities: management, operations, and fiscal environment* (pp. 129–53). Albany, NY: State University of New York Press.

Jimenez, E. (1986). The structure of educational costs: multiproduct cost functions for primary and secondary schools in Latin America. *Economics of Education Review*, *5*, 25–39.

Johnes, G. (1997). Costs and industrial structure in contemporary British higher education. *Economic Journal*, *107*, 727–737.

Koshal, R. K., & Koshal, M. (1995). Quality and economies of scale in higher education. *Applied Economics*, *22*, 3–8.

Koshal, R. K., Koshal, M., Boyd, R., & Levine, J. (1994). Tuition at Ph.D. granting institutions: a supply and demand model. *Education Economics*, *2*, 29–44.

Langston, I. W., & Watkins, T. B. (1980). Sat–act equivalence. *Research memorandum 80-5*. University Office of School and College Relations, University of Illinois.

Lloyd, P. J., Morgan, M. H., & Williams, R. A. (1993). Amalgamation of universities: are there economies of scale or scope? *Applied Economics*, *25*, 1081–1092.

Management Ratios No. 7 for Colleges and Universities (1993). Boulder, CO: John Minter Associates.

Mayo, J. W. (1984). Multiproduct monopoly, regulation, and firm costs. *Southern Economic Journal*, *51*, 208–218.

Nelson, R., & Heverth, K. T. (1992). Effect of class size on economies of scale and marginal costs in higher education. *Applied Economics*, *24*, 473–482.

Ramsey, J. B. (1969). Tests for specification errors in classical linear least squares regression analysis. *Journal of the Royal Statistical Society Series B*, *31*, 350–371.

US Department of Education, National Center for Education Statistics (NCES) (1993). Compact disk: Integrated Postsecondary Data System (IPEDS), Finance Survey, 1990–91; Final Release and Fall Enrollment Survey, 1990.

Verry, D., & Davies, B. (1976). *University costs and outputs*. Amsterdam: Elsevier Publishing.

Verry, D., & Layard, P. R. G. (1975). Cost functions for university teaching and research. *The Economic Journal*, *85*, 55–74.